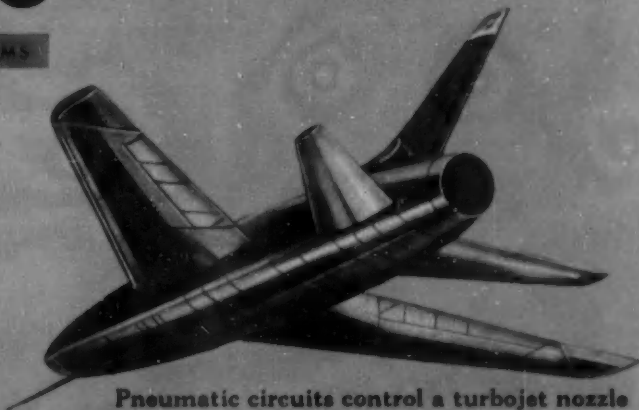
Control ENGINEERING

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

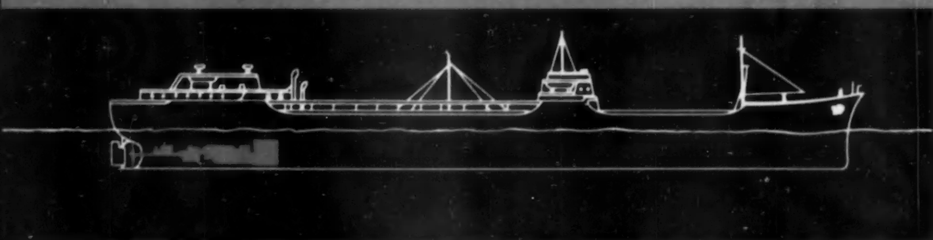
A McGRAW-HILL PUBLICATION

PRICE 50 CENTS

OCTOBER 1956



Pneumatic circuits control a turbojet nozzle

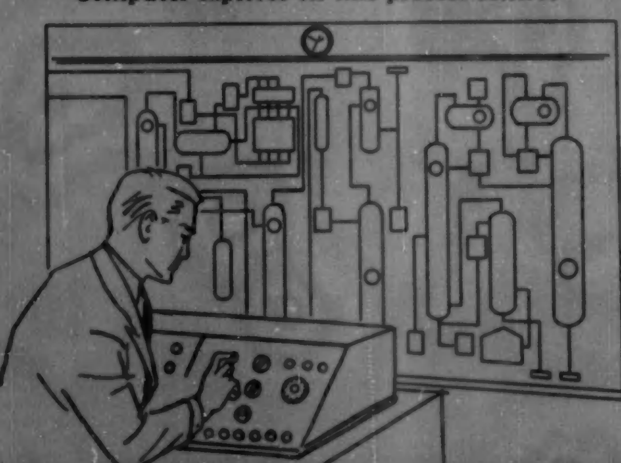


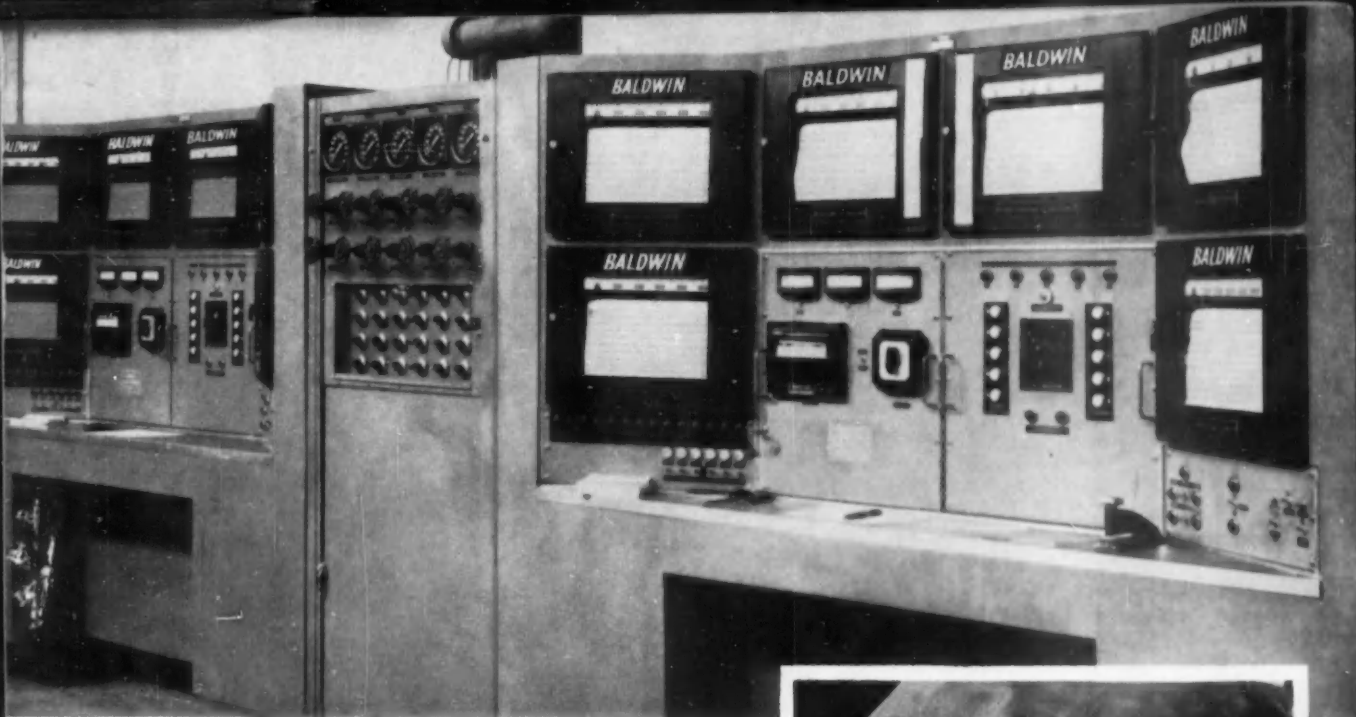
Integrated system will control atom-driven shipboard turbine

Progress in Control

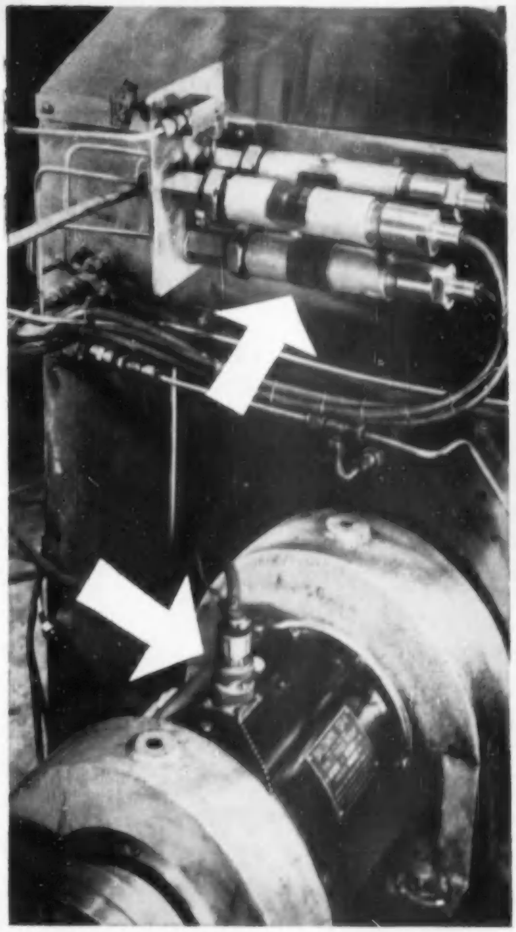
Whirlwind programs a machine tool for control

Computer explores on-line process control





jet engine starter performance plotted quickly and accurately by Baldwin SR-4® system



Under simulated operating conditions, turbine type fuel-air combustion starters for jet aircraft engines are performance-tested by a Baldwin instrumentation system that is instantaneously responsive and accurate to .1%.

Starter operating characteristics are measured by three Baldwin SR-4 strain gage type pressure cells (at top of photo at right) and an SR-4 torque pickup (below) which follow variations in combustion pressure, fuel pressure, air pressure and torque. Electrical signals are transmitted from the cells and plotted on Baldwin recorders mounted in control consoles (photo above). Also plotted are primary ignition voltage and shaft speed. With this instrumentation system one test engineer can conduct 3½ second test runs on a continuous basis.

If *you* need to measure torque, pressure, load, tension or thrust, Baldwin can custom-design and build a system to do the job. "Packaged" systems and component transducers are also available. For illustrated bulletins, write us at Dept. 3152, Waltham, Massachusetts.

SEE OUR EXHIBIT AT THE AUTOMATION SHOW

BALDWIN BLH LIMA-HAMILTON

ELECTRONICS & INSTRUMENTATION DIVISION

BALDWIN-LIMA-HAMILTON

DIVISIONS: Austin-Western • Eddystone • Hamilton • Lima • Loewy-Hydropress • Madsen • Pelton • Standard Steel Works

Published for engineers and technical management men who are responsible for the design and application of instrumentation and automatic control systems.

Control ENGINEERING

INSTRUMENTATION AND AUTOMATIC CONTROL SYSTEMS

OCTOBER 1956

FEATURE ARTICLES

IDEAS AT WORK

DEPARTMENTS

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SHOPTALK

PROGRESS IS OUR . . .

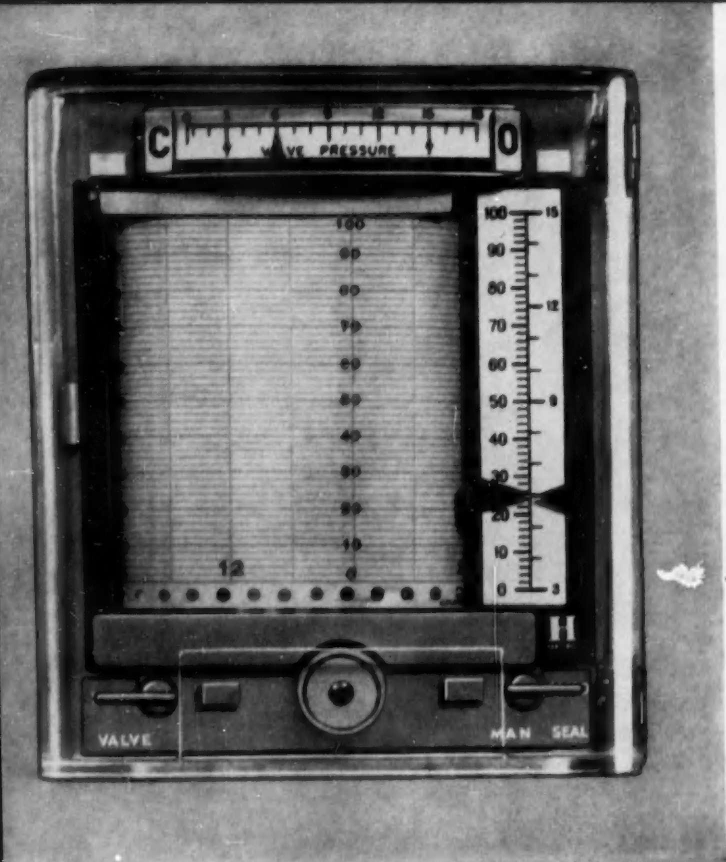
. . . cover theme this month. The four situations deployed by Art Editor Jack Gordon against one of his typically un-sombre background colors tell of specific progress through control on sea, in the air, on machine, and in process. And the articles within prove, we hope, that our cover theme is not just a singing commercial—but that control engineering continues to spur important progress across all fields. According to Webster, progress is, among other things, "an advance to an objective". What could illustrate this point more boldly than the du Pont-Burroughs experiment in real-time process computing described on page 24? The advance is, of course, the practical proof that this story brings concerning the successful integration of a general purpose computer into an existing system of industrial measuring and transmission devices. A step toward what objective? Why merely the truly-automatic industrial plant.

MOST IMPORTANT . . .

. . . in Webster's definition, however, is that progress is a "gradual betterment". Two feature articles underscore this point. Wendell Reed's story on page 92 tells how the performance of an aircraft power plant has been bettered by a new, simplified pneumatic computing control. (Reed got a Wright Brothers' Medal for reporting this work to SAE last fall.) And Arnold Seigel's step-by-step picture of a disarmingly simple method for programming a machine on tape (see page 65) proves that better, less harried days lie ahead for the users of numerical control. Webster also calls progress a "journeying forward", and to fit this concept we have called on Milton Lowenstein, in his article on page 71, to tell how control techniques will harness the first nuclear drive in an ocean going cargo ship.

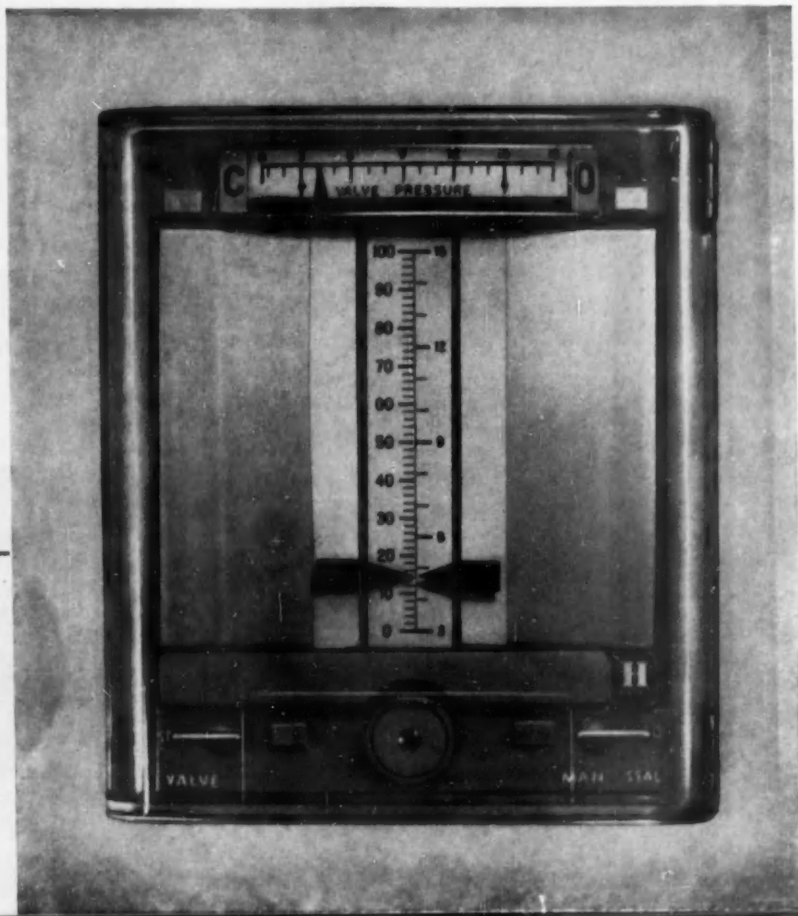
PRODUCT . . .

. . . makers also meet the test of Webster's definition—in this case a "going or getting ahead". Industry's Pulse this month, page 55, unveils this kind of progress among a group of typical suppliers to our field, as gleaned from a survey of their annual reports. So investors in control—be ye coupon clippers and/or readers of CtE—perhaps you would like to join us in coining this pluplagiarized motto: If It's Control You Can Be Sure that Progress is Its Most Important Product.



for simplest

Both the *Tel-O-Set* indicator and recorder have vertical indicating scales on which large, opposing pointers clearly show measured value and set point. The control knob and transfer switches are located near the bottom of the case, where they can be manipulated without the operator's hand obscuring the view of the pointer and scale.



● **REFERENCE DATA:**

Write for Bulletin 7202.

FEEDBACK

Bravo

TO THE EDITOR—

Reading your July issue, we notice on page 67 your discussion of classification of instrument data by the Census Bureau. This touches a subject on which we have been long interested and on which practically no information has been available. Elsewhere in the same issue you have some figures on total business of the instrument industry, and *Business Week* published some similar information about three months ago. Other than the publications of these two magazines, we have never seen any reliable figures on instrument industry totals.

Anything you can do to get the Department of Commerce to establish a correct and complete classification of the instrument industry would be of great value. It is not surprising that they do not have this information because the industry has hardly been recognized as a separate entity for more than the last 10 years.

Best wishes in your efforts and we certainly hope you can get some kind of satisfactory results.

H. F. Barrett
Buffalo Meter Co.
Buffalo, N. Y.

The Department of Commerce is now reviewing the Standard Industrial Classification. Undertaken primarily at the request of industrial groups, the review will take into account the significant changes which have occurred in industry organization since the latest SIC was issued (1942). Industry groups and Federal Statistical agencies are invited to participate in the review which is coordinated through the Bureau of the Budget.

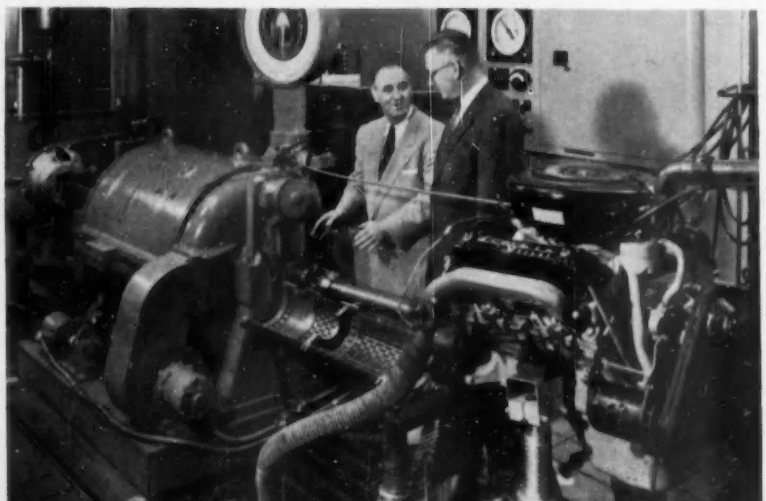
We have suggested to the Bureau of the Budget this functional structure for the instrumentation and automatic control field:

XX1–Sensing and Measuring Equipment
XX2–Data processing and Transmitting Equipment
XX3–Controlling and Decision-Mak-

(*Continued on page* 12)

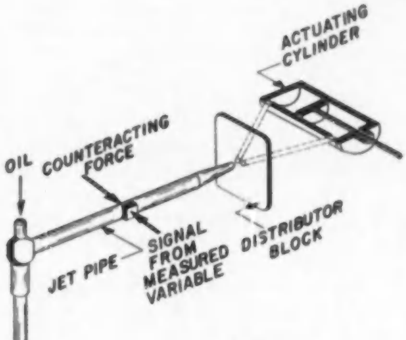
"Progress is our most important . . ."

. . . service, with apologies to the employer of E. S. Dygve, a contributor to the article, "What Price Performance?", page 162 of last month's issue. Figure 1 in the article showed a 200-hp dynamometer testing an automobile gasoline engine. But Ford and GE progress: dynamometer ratings have risen to handle the increased horsepower of Ford engines. The photograph immediately below shows C. E. Patterson, manager of the Dynamometer Dept. of the Research & Engineering Center of the Ford Motor Company, and C. P. Vest, manager of automotive sales of the Apparatus Sales Div., General Electric Co., Michigan District, viewing a 300-hp dynamometer currently running performance tests on the 1956 Lincoln V-8 275-hp engine. YOU CAN BE SURE that the dynamometer and its controls were furnished by GE. Ed.



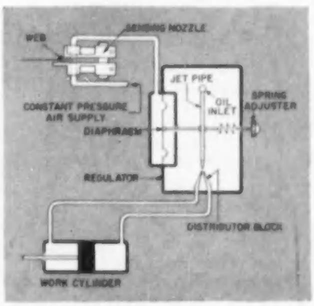
Key Component for Automation...
The ASKANIA Jet Pipe Relay

Modern Controls Demand



Standard Askania Jet Pipe Regulator

The ASKANIA Electro-Hydraulic Valve Actuator—the "missing link" in electronic control—which makes electrical operation of the final control element a reality for the first time. Write for Bulletin #200.



APPLICATION

Illustrative of the far-reaching potential of hydraulic control applications is the ASKANIA non-contact edge position control which has been successfully used by paper, metal and textile industries, to automatically maintain accurate lateral positioning of moving material in winding, unwinding and guiding operations in various processes where the edge of the material must be maintained within limits of as low as 1/64". Write for Bulletin #161.

SPEED • ACCURACY
HIGH POWER LEVELS • LOW MAINTENANCE
RELIABILITY

If you are concerned with automatic controls for production or any other function, you'll find the ASKANIA Jet Relay the answer to your problem; through the application of HYDRAULIC force it provides the speed, accuracy, high power level, low maintenance, and reliability you need for top results.

HOW IT OPERATES: A stream of oil is supplied under pressure to the stem of a jet pipe tube which ejects it with high velocity.

Depending on the position of the jet relative to close adjacent receiving orifices a pressure differential is created on a double-acting piston varying from zero to a maximum in either direction.

Thus a speed and force proportional to relay displacement results in modulated, stable, practically instantaneous control action.

THE JET PIPE RELAY IN HEAVY INDUSTRY

For a quarter of a century, ASKANIA Jet Relays have been used for combustion, pressure, and flow control plus the control of other critical operating conditions in steel and coke plants, power stations and other heavy industry. They have been used to:

1 • Increase production **2** • Improve and maintain quality
3 • Save fuel **4** • Reduce maintenance costs

A NEW ERA . . . ELECTRO-HYDRAULICS

ASKANIA's Electrical Control of the hydraulic jet introduces the very important new technology of ELECTRO-HYDRAULICS . . . *combines the versatility of electronic systems with the flexibility and tremendous, instantaneous power of hydraulic force.*

Electro-hydraulic controls can be made to respond through transducers to any plant variable or be used as a powerful servo to computer output signals (digital or analog). Bulletin #38.1. An excellent example is the self-contained ASKANIA Electro-Hydraulic Valve Actuator . . . a successful combination of electric and hydraulic technology.

INFORMATION ON OTHER ASKANIA CONTROLS

Here are some other useful ASKANIA Controls. Write for the descriptive bulletins for answers to your specific problems.

POSITIVE DISPLACEMENT TRANSOMETER—for measuring, controlling, and integrating flows of fuel oils, viscous liquids, and other liquids. (Bulletin #301)

POWER PACK REGULATOR—for use as relief or reducing valve; control of fluid flows or as remote valve positioner. (Bulletin #165)

UNIT REGULATOR—for pressure, flow and ratio control applications. (Bulletin #155)

Write ASKANIA Regulator Company, 266 East Ontario St., Chicago 11, Ill.

***ASKANIA* REGULATOR COMPANY**
"CONTROLS FOR INDUSTRY"
HYDRAULIC, ELECTRONIC CONTROLS & SERVOS, GENERAL SYSTEMS, ENGINEERING & COMPUTER SERVICE, VALVE ACTUATORS & CYLINDERS
A SUBSIDIARY OF CPE

THE PROBLEM FORUM . . .

No problem is posed this month. Instead we present a frequency response spectrum of typical equipment available for industrial control. The author of the spectrum offers it to encourage others to gather and publish similar data. Send in yours, documented with complete information on test conditions and test apparatus. We will pay honoraria for those accepted and published.

To the Editor—

Here (see cut below) is my "Electro-Mech-Hydro-Pneum-Nuclear Frequency Spectrum". The data are approximate. Bandwidths for reset and rate refer to the corner, or break, frequencies of those control actions. For those who are interested in the transient response to step changes, the approximate equation

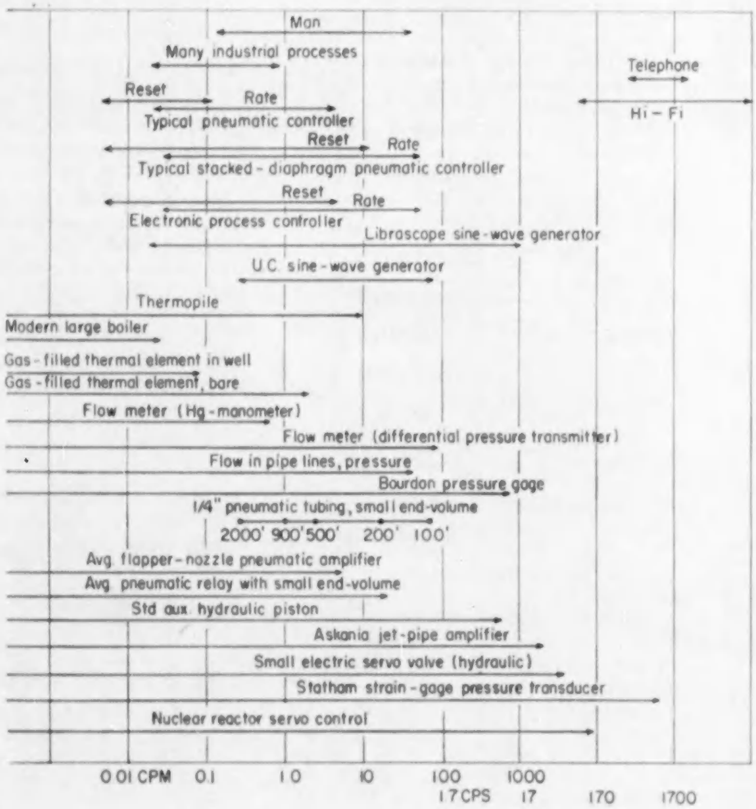
$$(\text{Response Rise Time}) \times (\text{Bandwidth}) = 0.30 \text{ to } 0.45$$

will relate frequency response to transient response. Response rise time is "usually defined either as the time required for the response to go from 10 to 90 percent of its final value, or as the reciprocal of the slope of the response at the instance the response is half the final value", see pages 79 and 80 of "Automatic Feedback Control System Synthesis", J. G. Truxall, McGraw-Hill Publishing Co., New York, 1955. The value 0.30 refers to a response with negligible overshoot and the value 0.45 to a response with about 10 percent overshoot.

A wall chart, or several pages in a handbook, containing the frequency spectrum of this and other available equipment would, it seems to me, be very useful to control engineers.

H. Thal-Larsen
University of California
Berkeley, Calif.

We agree. Some of the necessary data will be included in the forthcoming sequels to R. P. Bigliano's article, "Measuring the Dynamics of Pneumatic Components", published in our August '56 issue. Data on the dynamics of valve actuators appeared in C. D. Close's article, "Valve Actuators Tie Precision to Power", a feature of the September '55 issue. Submit your data, readers. CtE will see that it is correlated and published. Ed.



POTPOT
POTENTIOMETERS

"Potpot" encapsulated potentiometers are available in either wire-wound or composition-element types, including Clarostat Series 48M and 49M miniatures, and in Series 43, 37, 51, 58 and 10 controls.

New encapsulating material provides water- and vapor-tight molded enclosure imbedding entire unit with exception of external shaft assembly and terminal tips. Special water-tight assembly for shaft bushing.

Designed to meet MIL-STD-202 Test Specification. Incorporating necessary salt-spray, humidity and temperature-cycling requirements of MIL-E-5272 climatic standards. Excellent shelf life.

Write for complete details.

CLAROSTAT®

CONTROLS AND RESISTORS

CLAROSTAT MFG. CO., INC.
DOVER, NEW HAMPSHIRE

ing Equipment
XX4—Actuating and Decision-Effecting Equipment

The structure must be filled in and tested on the marketing people in our field. We would like to have, from our readers, suggestions for filling it in. Ed.

Red Sales in . . .

To the Editor—

The photographs taken by your correspondent, Mel Fusfeld, at the Milan Fair have been of great interest to many of us here at L&N.

The Russian-made instruments exhibited at the Milan Fair appear in certain respects to be "Chinese copies" (i.e., "Red"-Chinese copies) of Speedomax Recorders. This is simply another illustration of what is becoming painfully evident to everyone—namely, that in spite of the most stringent regulations and the most scrupulous following of them, it seems impossible to prevent an iron-curtain country from getting products through devious channels and copying them.

Kenneth W. Conners
Leeds and Northrup Co.
Philadelphia, Pa.

Feedback corrects . . .

To Charles W. Adams—

In the June 1956 edition of Control Engineering there appears on page 105 an article headed "Processing Business Data" and indicating that you are its author. The article has been read and studied by a number of people and many have commented on the outstanding manner in which you present the functions of business data processing systems and how these (data processing systems) differ from those used to solve scientific problems or to control industrial systems. There is no doubt that your article is timely and informative and should prove of real assistance to those who are now contemplating data processing operations.

We note that in the chart "The Routine of Business-Data Processing", in the section blocked out as File, you refer to "Juke box of magnetic tape strips (Potter RAM, Telecomputing RAMAC)". We believe you will be interested to know that RAMAC is a registered trademark of International Business Machines Corporation, U. S. Trademark No. 627359, issued May 22, 1956, and its use is authorized

FEEDBACK

only in connection with our products.

F. J. Wesley
International Business Machines Corp.
New York, N. Y.

. . . and author recants

To the Editor—

I incorrectly used the term RAMAC in referring to the MASS unit once under development by the Telecomputing Corporation. The fact that I once had these names straight is borne out by my reference to them in an earlier article for Special Report No. 3 of the American Management Association (page 135).

Charles W. Adams
Creole Petroleum Corp.
Caracas, Venezuela

Pinpointing references . . .

To the Editor—

In the June 1956 issue of your magazine, you ran an article entitled "What to look for in Electrohydraulic Servo Valves".

At the end of this article, references were made to four technical reports. Would it be possible for you to advise me as to how these reports might be obtained. Any help you can render along this line will be greatly appreciated.

Roy Rosebrook
El Monte, Calif.

We suggest that you request copies of the listed references by writing to the authors or their affiliated organizations at the addresses given here. Ed.

1. **HYDRAULIC SERVO CONTROL VALVES, R. E. Boyer, B. A. Johnson, L. D. Schmid, Parts I and II, WADC Technical Report 55-29, Cook Research Laboratories. Address: 2700 Southport Ave., Chicago 14, Ill.**
2. **CONFERENCE ON HYDRAULIC SERVOMECHANISMS, The Institute of Mechanical Engineers, February 1953. Address: 1 Birdcage Walk, Westminster, London S. W. 1, England.**
3. **DYNAMIC CHARACTERISTICS OF VALVE-CONTROLLED HYDRAULIC SERVOMOTORS, J. L. Shearer, "ASME Transactions", August 1954. Address: Mechanical Engineering Dept., MIT, Cambridge 39, Mass.**
4. **A METHOD FOR THE SELEC-**

TION OF VALVES AND POWER PISTONS IN HYDRAULIC SERVOS, F. C. Paddison and W. A. Good, Johns Hop-1952. Address: Baltimore, Md. kins University, CM 717, January

A Patent Dead End?

To the Editor—

I have recently stumbled onto or into something that I must tell somebody.—

A Los Angeles man, Mr. Pulliam, formerly an electronics production engineer for North American Aviation, was stricken with bulbar polio about three years ago. His life saved, he today runs a shop employing about 15 people while sitting in a wheel chair, paralyzed from the collar bone down except for one big toe. Three minutes stoppage of the main and auxiliary air pumps to his "iron lung" and he is dead.

Mr. Pulliam asked me if I could devise some means whereby he could authorize (by signature) a check acceptable to a bank. I immediately thought of his using his voice to actuate a mechanism that would accomplish the signing, the mechanism being in his presence and sealed. An alarm he would ring would ward off an attempt to use the mechanism by a "mimic". The idea required a patent research in which I discovered the following:

The "tape recorder" complete with sideband (Westinghouse) recording was patented on Nov. 8, 1932 by a Mr. J. G. Alverson. This exact invention was repatented almost immediately after Alverson's patent expired in 1949 (Patent #1,886,616) by I.I.T., Chicago. Electronic experts have told me the two inventions are identical.

I found another instance of repatenting, a digital relay application, patented to my certain knowledge in 1935 (by North Electric Co., Gallion, Ohio) and produced by Westinghouse. Existing equipment is right now in service in the Santa Monica and Pacific Palisades substations of the L. A. Dept. of Water & Power. This patent expired in 1952 and was repatented in 1953 by others, Patent #2,628,277.

Furthermore, the Westinghouse "Televox" (Wensley) was demonstrated to the public utility industry in 1927. I assumed that the expired patent was being used as prior art by the General Control Div. of Minneapolis Honeywell in their 1953 version of

"audio pitch" supervisory control. Now, I discover that this was repatented in 1956 under Patent 2,577,614, reissue 24117, but not to Wensley.

But on the core of voice control, I found two patents—2,575,909 and 2,575,910—which covered voice control as I would use it for Pulliam. The first, a means of "analyzing the progressive sound of a spoken word"—"standard word"—for "identification signal" is not applicable. But the second, to use unanalyzed voice wave by energy, maxima and minima, progressive match or mismatch, to operate control is exactly what I need. But the "energy" is decibels in a microphone, leaving the gain to be made up by means only left to inference. Obviously, the patentee was dealing in words and not realities. Otherwise, why hasn't he put on the market the device Mr. Pulliam needs?

Charles L. Kern
Sherman Oaks, Calif.

. . . Proceedings in the bag

To the Editor—

In the October 1955 issue of Control Engineering, you make reference to a "control" conference held at Purdue University on July 25th. Will the papers presented there be published in one volume? If so, how can I go about purchasing it?

Morton J. Roberts
Williamstown, N. J.

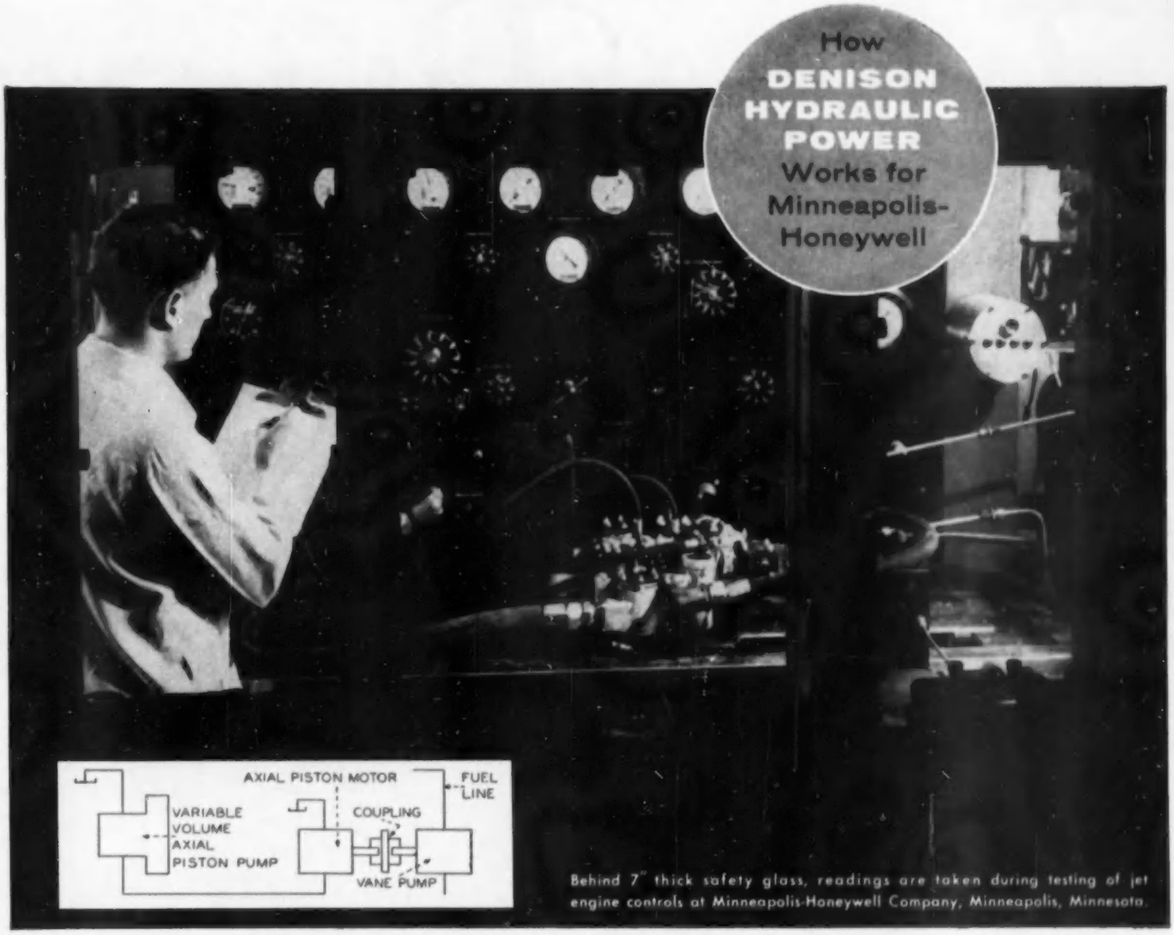
Mr. Roberts' letter came in many moons ago, but we were unable to answer him until we received, in response to our query to Purdue University, a copy of the "Proceedings". An inch thick, it contains Multilithed copies of the papers presented. To quote from the foreword, the conference "emphasized industrial process control and summarized the modern applications of servo techniques, computers, and network theory to this field." Interested readers might contact Professor J. M. Cage, Electrical Engineering Dept., Purdue University, Lafayette, Ind. Ed.

Marks for "Regelungstechnik"

To the Editor—

You were so kind to mention our publication, *Regelungstechnik*, in your publication. Apparently it was pointed out that our publication may be obtained through the publishing post office of the German Democratic Republic. We would appreciate that future inquiries of your readers be directed to our address:

Verlag R. Oldenbourg GmbH
Rosenheimer Strasse 145
Munich,
Federal Republic of Germany



Behind 7" thick safety glass, readings are taken during testing of jet engine controls at Minneapolis-Honeywell Company, Minneapolis, Minnesota.

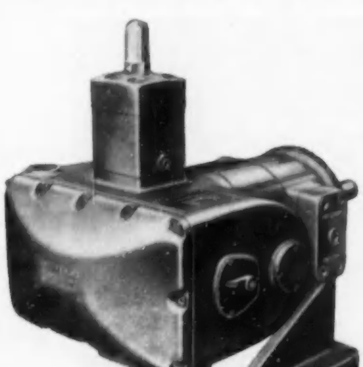
Providing the muscle power for a "ghost" engine

A unique electronic system developed by Minneapolis-Honeywell to pre-test jet engine controls now eliminates the cost of building and operating a special engine test cell. The system actually produces a more accurate record of performance than would be possible if the actual engine were used.

The system works this way. An analog computer takes the place of the jet engine. Performance data and other characteristics are received from the manufacturer. These are then simulated on the computer and reproduced as electrical signals, which, in turn, run the engine controls.

To provide dependable muscle power for this control system, Minneapolis-Honeywell relies on Denison hydraulic pumps and motors. The key unit, a Denison Variable-Volume Axial Piston Pump is the prime mover for a Denison axial piston motor that in turn powers a Denison vane pump to deliver jet fuel.

Denison hydraulic equipment is today serving all industries by cutting operating costs, speeding production, and improving reliability. Let a Denison field engineer show you how you can benefit from Denison's hydraulic experience. Write Denison Engineering Division, American Brake Shoe Co., 1247 Dublin Road, Columbus 16, Ohio.



Denison Variable Volume Axial Piston Pump remote controlled.

DENISON HydrOILics

HYDRAULIC PRESSES • PUMPS • MOTORS • CONTROLS

Progress Report:

SCHRADER AIR PRODUCTS SATISFY AUTOMATION'S NEED FOR SPEED

Modern production quotas make speed essential

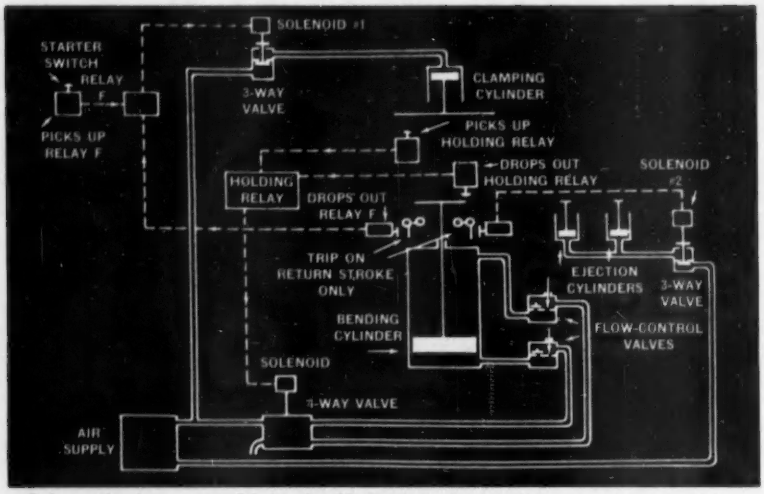
Air has always been fast acting. Its speed has made it useful in holding and releasing work fast, in blasting away scrap or waste. And today's need for speed is one of its most valuable features. In past years, the very simplicity of air often made industry lose sight of its possibilities for more complicated, essential procedures. But industrial imagination is fast catching up with itself. Hundreds of Schrader Air Products, precision-machined and extremely versatile, have opened the way to almost limitless production possibilities. The need for more units in less time through automation has found air ready, willing and able. In recent years, the natural speed of air for performing necessary functions is being utilized on a constantly increasing scale.

FOR EXAMPLE:

Burner grill production quadrupled

Bending metal rods for kerosene burner grills requires a ton of force at an oil burner corporation in Hartford, Connecticut. Before air was adapted to the job, only 150 pieces per hour could be produced. Now, with the help of Schrader Air Products, 620 pieces are produced every sixty minutes.

The accompanying schematic shows the simple arrangement of Schrader Air Products which the company developed with the help of Schrader engineers. The rapidity achieved in production, amazingly enough, is coupled with much greater safety and economy, two other features inherent in the use of air.



Schematic shows use of Schrader Air Products for bending metal burner grills.

Automation capabilities of Air as seen in Cylinders

Schrader Air Cylinders deliver a push, or a pull—or a pull and a push—in any direction from almost limitless positions. They will deliver a greater straight line force than that obtainable in any commonly used type of power unit of equivalent size and weight. You get strength to spare and speed to burn. Large air ports provide fast starting action for rapid cycle work. Wide interchangeability of parts gives an added premium of reduced maintenance costs.

A survey of your production machinery will reveal many instances where an air cylinder can be used to save space, time and money. Many manufacturers of original equipment are now studying the advantages of applying this low cost, universal means of supplying force to products of their own design and manufacture. They are finding that air cylinders can easily be utilized to eliminate costly mechanical movements, tiring manual labor, and space consuming mechanisms.

Schrader engineering facilities are at your disposal

Upon request, Schrader engineers will assist in planning for the most efficient use of air in your plant, and in selecting the products best suited to a given application. Distributors are conveniently located to deliver Schrader Products in the shortest possible time. Today, these products are being turned out in mass production quantities for scores of industries. New products are also being designed constantly as acceptance of Schrader's know-how grows.

Write to Schrader for information.

Address A. Schrader's Son, Division of Scovill Manufacturing Company, Incorporated, 471 Vanderbilt Avenue, Brooklyn 38, N. Y.

Schrader®
ESTABLISHED IN 1844

FIRST NAME IN THE USE OF AIR
FOR INDUSTRIAL PRODUCTION AND CONTROL

JAKE JAEGER
servos in machines

If you are one of those who are spinning on the tidal wave of excitement about the "revolution in automatic machining", go up to Connecticut for a visit with J. J. Jaeger at the busy, sprawling Pratt & Whitney Company plant and come up on dry ground. "Metal cutting," Chief Engineer Jake will tell you in his firm, easy manner, "is still in the age of guided muscles, not guided missiles. Automobiles have come a long way since the Model T—and so have machine tools. But you'd be unrealistic if you expect autos, at this stage, to simply go where you want by pushing a button." Then, once he's got you on dry ground, Jake will grin and take you on a tour of his shop for a realistic look at progress in automatic machining.

Jake Jaeger is uniquely qualified to speak for his industry on its control engineering prospects—for he is one of our country's original control engineers: he was in the group of pre-war graduate students at MIT who set the foundations for modern servo theory. And, says Gordon Brown, another member of the group, "Jake admirably carries that background into the work he is doing today."

Jaeger: "It looks to me that control will soon be 50 to 60 percent of the cost of a machine tool."

From 'phones to feedback

Jacob J. Jaeger was born in Philadelphia in 1909 and graduated at the top of his class at Drexel Institute (EE in '33). The school's cooperative program gave the budding engineer four six-month stints as a maintenance man for AT&T on its telephone repeater station equipment. Afterward, while on an MIT fellowship, Jaeger got interested in control and wrote his master's thesis under Harold Hazen on error-correction in a photoelectric curve follower (a device developed by Gordon Brown the year before). In '35 he became a research assistant under Vannevar Bush and spent the next four years in the study program guided by Sam Caldwell, which produced the electronic differential analyzer that finally replaced the famous mechanical computer at MIT. In this project the bulk of Jaeger's time was spent designing and perfecting servos and output readers, and, during the last year, fabricating what he calls "the last of the big analog ventures".

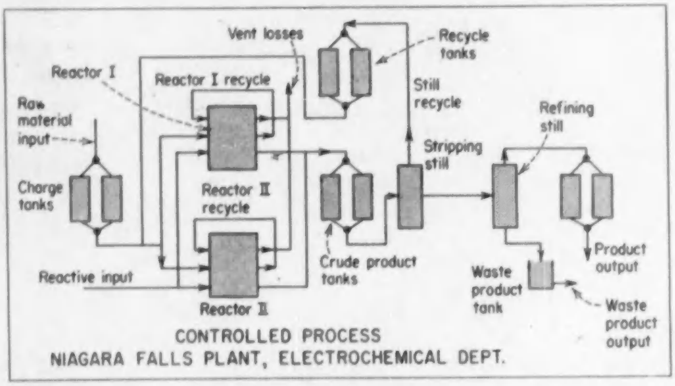
In 1940 Pratt & Whitney, searching for someone to spearhead improvements on its recently-acquired Keller tracer-control systems, brought Jaeger into its Development Engineering Department. For several years Jake applied servo techniques to perfect the tracer-follower—an effort that resulted in today's broad acceptance of Keller tracer-controlled millers by industry. In '45 he started work on other P&W machines and the following year was made head of the Experimental Section. One of the developments at this time was a magnetic-bar tool position measuring system (a noncontacting mechanical method accurate to 0.0001 in.) which later gave the company a head start in the digital field. A fast rise for Jake followed this productive period: in '49 he became assistant manager of Machinery Division Engineering; in '54 chief engineer; in '55 vice-president and chief engineer.

Away from the plant, Jake Jaeger keeps up the active pace on and around his eight rolly, stony Connecticut acres in the village of North Canton. His prime hobby at the moment is a project to encourage a deeper interest and feeling for nature in children (he has three, two boys, 16 and 2, and a girl, 6). He and his wife Dorothy, an artist, are hard at work helping build and outfit the Canton Children's Museum. Its two buildings already house an enviable collection of fluorescent minerals and mounted flora and fauna and is the site for enthusiastic meetings for small fry from miles around.

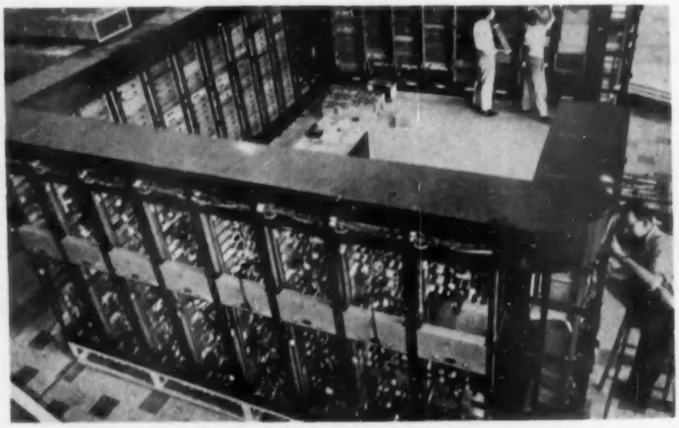
WHAT'S NEW

DIGITAL COMPUTER EXPLORES Real-Time Production Control

THE PROCESS subjected to real-time computer analysis was an operating unit in the Electrochemical Dept. of du Pont's Niagara Falls plant. The diagram at the right shows the flow sequence in a chemical reaction between liquid and gaseous ingredients. Eleven measurements from the process were fed into the computer to assay overall behavior from the standpoint of yield and efficiency.



THE COMPUTER used in the study was at the end of a leased wire in the Burroughs Computer Center in Philadelphia. It was programmed to calculate material balances and took into account the dynamic behavior of the process itself. Shown at the right is the UDEC-11 general-purpose digital computer that did the job. Information from it was retransmitted to Niagara Falls and to the du Pont engineering headquarters in Wilmington.



When control engineers from the process industries meet these days what do they talk about? Ike or Adlai? Perhaps. Deer and ducks? Maybe. But whatever the topic is, it's a good bet that it will eventually move over to make room for this one: The prospect of using a computer to control a process in a plant.

The experiment suggested in the pictures at the top of this page—a joint study conducted early this year by du Pont and Burroughs—is one of the first signs that some intense activity is forthcoming in computer process control. Another sign is the "sell out" at the special symposium on "Integrating the Computer into the Process Control Loop", one of the features of the current (Sept. 17-21) Instrument Society of America annual meeting in New York.

Formidable work ahead

Lip-service to computer control, however, is no sure promise of practical action. Most process control engineers well know the formidable work that lies ahead of them simply in attempting to program a computer to a working process. In his key paper at the ISA symposium, Prof. Don Eckman of Case Institute vividly cites the problem. In a pilot project to optimize by computer control a simple batch oil-hydrogenation process, said Eckman, 25 graduate students were kept busy for over two years studying the kinetics of the reaction, converting these to equations, and programming the latter into the computer. And then, after these "preliminaries", intense work had to be done to integrate the computer into a system of devices to automatically control the hydrogenator. And, Eckman holds, that's only the start. What such a project teaches may well lead to a monumental redesign of the process itself to increase its yield and controllability.

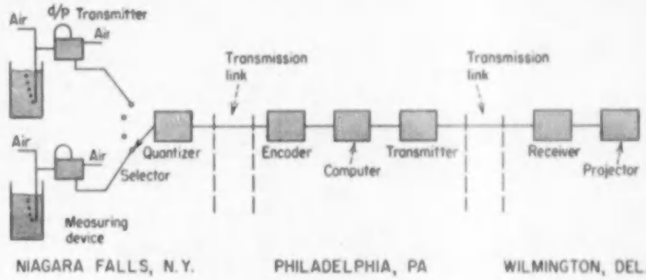
Crawl before you leap

While Case Institute's findings clearly state the whole problem, there are few in industry with the opportunity or proper manpower to make

the full-fledged introspective study of process dynamics which is needed before a computer can be brought into the control loop. This is why the du Pont-Burroughs project is so important—and timely. It illustrates a realistic exploratory method for testing the possibilities for a computer in a process plant, a method by which one eases rather than leaps into the problem of computer process control.

Burroughs and du Pont teamed up on their project early this year when a portion of the electrochemical process in Niagara Falls was made available to Wilmington control engineers and UDEC-11 was programmed for the problem. The test period lasted four days and during that time several computer runs were made—the longest continuing for four straight hours.

But let's get the story straight from the horse's mouth (in this case, horses' mouths).



THE SYSTEM employed by du Pont-Burroughs is diagrammed above. Levels from vessels were measured, converted to flow rates, then encoded into electrical pulses by a Bristol Metameter transmitter. The acoustical output, carried over leased 'phone line, was read by a microphone, converted to counts, and fed to the computer. Computed results went onto tape and were transmitted by teletype.

WHY DU PONT AND BURROUGHS CONDUCTED THE STUDY PROGRAM

A special contribution by E. W. JAMES and J. JOHNSTON Jr., E. I. du Pont de Nemours & Co., and E. W. YETTER and M. A. MARTIN, Burroughs Corp. Industrial Instrument Group.

Although the desirability of computer control for chemical processes has been recognized for some time, at least three important questions must be answered before a specific application can be tried:

1—What are the specifications of a computer suited to industrial process control?

2—Can the computer be tied in with standard industrial instruments?

3—What form should production control information take?

In an attempt to find answers to these broad questions a cooperative program was arranged between research people in Burroughs and personnel from du Pont's Engineering Dept. Burroughs agreed to provide time on its large-scale digital computer in Philadelphia for several days of online connection to a du Pont operating process. People in du Pont's Niagara Falls plant—long interested in the problem—volunteered to join in the test. A working team was then established consisting of du Pont plant technical, operational, and maintenance representatives, and instrument and communications engineers; and Burroughs computer programmers and mathematicians.

DESCRIPTION OF TEST

The process chosen was a chemical reaction between liquid and gaseous ingredients, with liquid product transferring through tankage from one stage of reaction to the next. Our aim was to use the computer to get suitably averaged production, transfer, yield, and loss figures at intervals frequent enough for rapid evaluation of process behavior.

Eleven measurements were selected to represent the instantaneous condition of the operation. Continuous inventory figures were determined using ten tank-level measurements and one measure of chemical composition. Each level was scanned by standard transmitters using electrically-programmed solenoid valves in each pneumatic output. The pneumatic signals were then converted to trains of electrical pulses for transmission via telephone line.

In Philadelphia the incoming pulses were fed into the computer which translated them into the binary code used by the machine. A special computer program had been devised to calculate flow rates from tank level changes. This program also included information on the dynamic behavior of the process. The resultant instantaneous flows were then used to continuously correct and indicate the inventory, yield losses, etc.

WHAT WERE WE AFTER?

The information required immediately from the computer concerned its assay of production quantities and production efficiency. Other data—of lesser value—involved facts on material balance and unaccounted-for losses. The specific figures computed were selected to be helpful to an operator in guiding the process. They covered the following items:

1—Total raw material transferred into the process
2—Total product produced
3—Production rate in lb/hr averaged over each half-hour
4—Overall yield
5—Yield rate averaged over each half-hour
6—Material balance and accumulated losses around the reactor section, the still section, and the complete process

A complete computation providing all the above results was performed every 6 min. And in order to present more realistic figures and eliminate

THE QUANTIZATION

of data from the Buffalo process to the Philadelphia computer was performed by combining a pneumatically-actuated time-interval telemetering device (Bristol Co. "Metameter") with a 1,000-cps fixed-frequency oscillator. Process measurements were selected in sequence by switching solenoid valves in the output pressure lines from each measuring instrument. Final output was in form of a group of 1-millisec pulses, the number of which was a measure of the variable.

large instanteous fluctuations, all rates were computed as running averages over five measurements (30 min).

WHAT WE FOUND OUT

Besides satisfying our quest for information on the three basic questions (computer specs, instrument tie-in, and type of production control data), the project gave us an unexpected bonus: it produced results of potential interest to operating departments. The close examination afforded by the use of the computer uncovered a number of operational procedures which could be improved.

Essentially, the project proved—

- ▶ the feasibility of intermediate-sized computers to control plant operations
- ▶ the unique method of telemetering by acoustical coupling
- ▶ the continuous presentation of numerical values to control production scheduling
- ▶ the form of production control information needed for quick operator decisions
- ▶ the type and size of digital computer required for industrial control calculations

The type of computer required for the computations in this test must have sufficient speed, approximately 1,800 single-address instructions, and 350 memory locations for storing the temporary results. With the large-scale computer in Philadelphia, the actual computation time was less than 20 sec. The time required for punching the teletype tape was approximately 15 sec, and the time needed to print the 11 inputs was approximately 30 sec. Hence, less than 65 sec after the last input signal came from a batch, the computer was ready for the next synchronization signal (which came 5 min later in the test).

Instrument inputs marginal

The test also disclosed several areas where work is needed before such a system could be considered efficient. Its use of standard industrial instruments to measure input variables to the computer proved only marginally satisfactory, and statistical averaging to improve the reliability of standard instrument readings was found to be inadequate. However, the method for encoding analog values taken from the standard instruments (see illustration above) was highly satisfactory and the transmission using this quantizing system was noiseproof. It was apparent during the test that there is an urgent need for measuring devices and transducers with inherently high degrees of accuracy, as well as a need for a foolproof reliable scanning system which combines durability with the speed necessary for adequate control.

Spot improvements

Experience gained in the project also unearthed some errors in calibration and indicated several areas where the instrumentation, data transmission, and computational program could be improved.

In the instrument system, the use of flow-rate meters in all internal portions of the process is recommended. This eliminates the conversion from level to flow and should remove some noise in the results. In cases where tank measurements are necessary, such as in the determination of inventory, baffles should be installed in the tanks to eliminate surface ripples and thus reduce signal fluctuations which harm the computer program.

While the system used for sequential selection and data quantization was simple and performed quite well as a whole, improvements could be made at some points. For one thing, calibration checks could be eliminated by a crystal or fork-controlled oscillator; for another, any variation due to power frequency draft could be removed by a fork-controlled constant-frequency power supply for the synchronous cam drive in the Bristol Metameter. An entirely separate buffer storage for accumulating data as coded would also be desirable, since it would eliminate loss of information when computer overflows occur and would permit continuous reception of data independent of program errors, computation errors, or other failures in the computer.

Several times in the computational program, computed results were in error because of unforseen manual manipulation at the plant. For example, liquid was removed from the charge tanks on several occasions without notifying the computer facility. Arrangements should be made in the future to transmit such information and insert it into the computer at the proper time.

EDITOR'S NOTE: This brief description of the du Pont-Burroughs project and its results will be followed by a feature article on the subject by the same authors next month. This second article will disclose the engineering details of system design and performance.

WESCON Bustles Through Its 10th Conclave

Pictured below are just a few of the highlights of the Western Electronic Show and Convention, held in Los Angeles Aug. 21-24. The 30,000 guests, 800 exhibits, and 200 papers made this year's conclave bigger, bouncier, more bountiful than ever. We'll publish the full report in November.

BEATING THE HEAT . . .

A tent bar outside, walking shorts inside, and an air-conditioned banquet were some of the ways they coped with "unusual" heat.

HEEDING THE BEAT . . .

Busy committee members kept track of hot events by portable radio intercom to a central communications post. Oh, yes: there was a sprightly use of 'phone service, too.

HEATING THE MEET . . .

Interest in new equipment in the booths was high, sometimes even fervent. The view at the far left shows a typical "jam session" in the IBM exhibit. What caused the commotion? The gentleman on the right is pointing the culprit—the new IBM magnetic disc, random access memory (RAM). Reason for the interest? The 50 rotating disc behind the man's elbow can store 5 million characters, yet access to any one of them is made in just one-half second on the average. And 20 more access mechanisms can be stacked on the original. 'Nuff said?

Tension Control Problems?

Dynamatic's Long Experience in Solving Industrial Windup and Unwind Problems will be Valuable to You

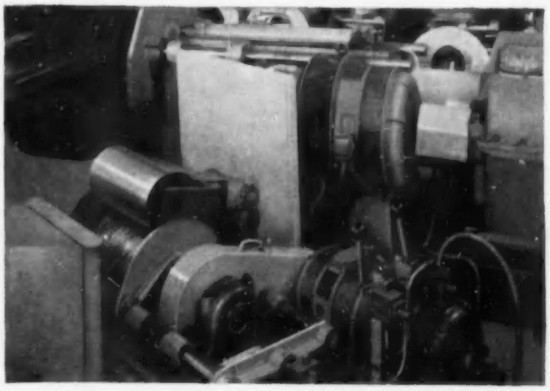
DYNAMATIC®

Dynamatic Eddy-Current Drives with tension controls are used extensively in the fields of paper, rubber, textiles, ferrous and non-ferrous metals, plastics, and printing.

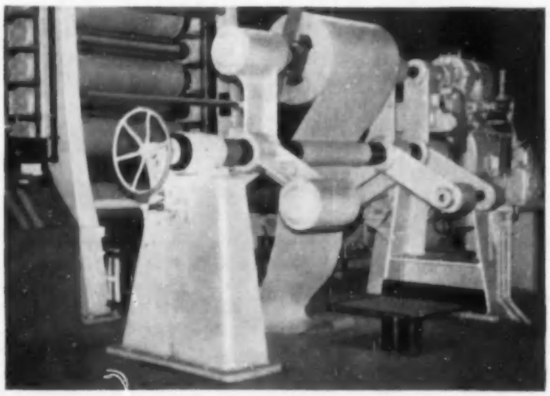
Combined with associated controls, Dynamatic Eddy-Current Drives provide automatic constant tension as the roll diameter changes on center rewinds and unwinds. Constant tension is maintained over a wide range of material delivery speeds without the use of dancer or follower rolls. Controls may be adjusted for tapered tension to increase or decrease tension automatically as the roll changes diameter.

Multi-range tension or tension adjustment over a wide range is easily accomplished at the operator's station to accommodate materials of various thicknesses or widths. Control modifications are available to provide for inertia compensation and other individual requirements. Dynamatic engineers are available for consultation on your problems.

Bulletins giving detailed information on Dynamatic Tension Control will be sent free at your request.



Metal slitter powered by Dynamatic Drives. Adjustable speed liquid cooled coupling used as main drive; Ajusto-Spede® Drives, with constant tension control, wind up the metal strips.



Completely Dynamatic driven paper super-calender. Adjustable speed liquid cooled couplings with Eddy-Current brakes drive the calender rolls and center rewinder. Dynamatic liquid cooled brake provides center unwind hold-back. Co-ordinated controls provide for wide-range adjustment of speed and tension.

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WHAT'S NEW

L'AUTOMATIQUE IN PARIS

Consulting Editor Gene Grabbe is seen below telling the First International Congress on Automation about recent gains in computing in the U.S. Avid faces indicate the interest.

CYBERNETIQUE IN NAMUR

A few days later a wider-eyed, deeper browed group met in this quaint Belgian city to hear experts like W. Grey Walter (second from right, below) discuss such things as "learning machines".

Control Technology Gets a Gallic Review

(as Grabbe reviews the Gauls)

PARIS, France and NAMUR, Belgium—European interest in "automation" and some of its more practical as well as esoteric aspects came to a high boil in these two French-speaking cities late last June. The two important conferences attracted an international group of distinguished scientists and control engineers—including a strong American contingent. A speaker in Paris and an interested visitor at Namur, CONTROL ENGINEERING's West Coast consulting editor, Dr. Eugene Grabbe of The Ramo-Wooldridge Corp., was good enough to send us his comments on the conclaves. We'll let Gene speak for himself below.

"About 1,000 delegates, including over 100 from Great Britain, Canada, and the U.S., attended this First International Congress on Automation in Paris. Other countries represented were Belgium, Brazil, Germany, Greece, Italy, Czechoslovakia, Yugoslavia, Norway, Sweden, Spain, and the U.S.S.R.

"An unusually congenial atmosphere prevailed, stimulated by the willingness of delegates to exchange information formally and informally, and by the gay life and fine restaurants of the City of Light. The purpose of the Congress was to cover the technical, economic, and social factors in automation, and the papers divided into three groups: 1) general; 2) applied; 3) production. The interests and backgrounds of those attending ranged from business and management to engineering and production—in this respect very similar to past conferences on automation in the U.S.

"The Congress opened with its President, M. H. Raymond (director of the French firm, Societe d'Electronique et d'Automatisme) emphasizing the need for diffusion of knowledge. M. Laval, director of Comfeogine Electromechanique, followed with a down-to-earth evaluation of industrial aspects of automation. Judging from the remarks, the situation in most European countries differs from the U.S. in that demand for products is smaller, capital is tighter, and attitude toward risk highly conservative.

Don Campbell stresses math

"Other outstanding personalities in Paris were Prof. Donald P. Campbell of MIT, and Prof. J. F. Coales, Cambridge University, both vice-presidents

WHAT'S NEW

of the Congress, and Boris N. Petrov, director of the Institute of Automation and Telemechanics in the U.S.S.R. In discussing the 'mathematical foundations of the production and service processes', Don urged that more time be spent in developing new methods rather than in trying to improve old ones. Petrov described work at the institute he directs—he covered systems analysis, simulation, and computing. He outlined an analysis of cross-servo relations and showed pictures of equipment developed for problem analysis. Current Russian efforts seem to be directed toward nonlinear systems, optimizing complex multivariable systems, and greater use of computers.

"Other papers of interest: W. S. Elliott of Ferranti described a vibrating wire analog-to-digital converter for pressure. R. Larguier, of Mark Wood (France) detailed a drag-cup motor with low inertia and high acceleration speeds. Your reporter outlined the pattern in use of computers in the U.S.–provoking a great many questions at the end. Dr. B. C. Leunke of Michigan State talked about computers in accounting and Dr. J. B. Rea kept the translators bewildered by his use of colorful stories to illustrate 'management feedback control'. Other sessions dealt with operations research and numerical control of machines.

"Away from the big hall the delegates and their wives kept busy with sightseeing, receptions, and banquets —where champagne flowed freely. Special events included a cocktail cruise on the Seine in the yacht of the President of France, a reception at the Town Hall of Paris, and visits to castles and chateaus not normally open to the public. As Don Campbell put it in the closing banquet, people who came to this Congress had a distinct advantage in coping with the leisure that will come from automation since they 'learned to play in Paris'.

On to Namur

"A short auto drive away into another country and I found myself among 800 persons predominantly scientists and academicians, attending the International Conference on Cybernetics held in picturesque Namur by the Belgian Ministry of Education and UNESCO–about 200 of the visitors were from 22 countries other than Belgium. The Conference gave most attendees their first opportunity to publically air their views on communications theory and cybernetics.

"The conference divided into four sections: 1) Principles and Methods of Cybernetics, presided over by Pierre Auger, professor of the Sorbonne; 2) Semantic Machines, presided over by Louis Couffignal of the Pascal Institute, Paris; 3) Automation, presided over by George Boulanger, professor at Mans and Brussels and president of the Congress; 4) Cybernetics and Life, presided over by W. Grey Walter of the Neurological Institute, Bristol, England.

"It was obvious in the early sessions that the speakers tended to shy away from definitions of cybernetics—since they felt this might impose restrictions on the scope of their activities. The general trend was to describe cybernetic systems as including the probability factors associated with life and living organisms (in other words, cybernetics steps in when automation has been carried to its limit). The difficulties rising with such a broad

AMERICANS IN PARIS

All was not pedantics and semantics at the Paris Conference on Automation. High up on the Eiffel Tower went Ramo-Wooldridge's (and CtE's) Dr. Gene Grabbe (right) along with J. B. Rea's Dr. Jim Rea (center) and MIT's Prof. Don Campbell. There, they report, "the winelike air purged us for the busy morning that followed."

Transitron

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HIGH CONDUCTANCE

RATINGS AT 150° C

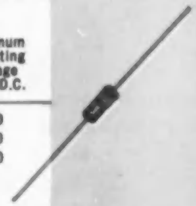
Type	Maximum Average Forward Current ma	Continuous Inverse Operating Voltage Volts D.C.	Minimum Saturation Voltage Volts
IN484B	50	130	150
IN486A	50	225	250
IN488A	50	380	420
IN457	25	60	70
IN458	25	120	135
IN459	25	180	180

HIGH FREQUENCY

SPECIFICATIONS AT 125° C

Type	Forward Current At + 1 V ma	Inverse Current At Specified Voltage ua at Volts	Maximum Operating Voltage Volts D.C.
IN252	10	10 @ - 5	20
IN251	5	10 @ - 10	30
S9G	2	10 @ - 20	40

Typical Shunt Capacitance: 0.8 uufd
Typical Pulse Recovery time: 0.15 usec
Operating Frequency Range: 0-1000 mc



Write for Bulletin TE-1350

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For low level power supply or magnetic amplifier service, the subminiature diodes or miniature rectifiers are recommended. For higher power requirements, the stud-mounted rectifiers provide up to 30 KW.

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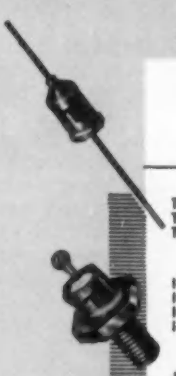
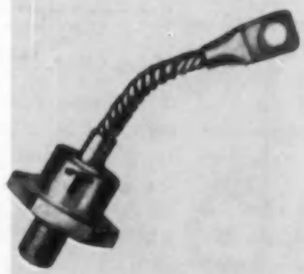


RATINGS AT 150° C

	Maximum Average Forward Current Amps	Peak Recurrent Inverse Voltage Volts	RMS Inverse Voltage Volts
Miniature (Pig Tail Leads)			
TJ10A	0.2	100	70
TJ20A	0.2	200	140
TJ40A	0.2	400	280
Military Types			
IN253*	1.0	100	70
IN254*	0.4	200	140
IN255*	0.4	400	280
IN256*	0.2	600	420
Medium Power Types			
IN249A	20	100	70
IN250A	20	200	140
TR352	20	350	250
High Power Types			
IN412A	35	100	70
IN413A	35	200	140
TH352	35	350	250

* JAN types Rated at 135° C



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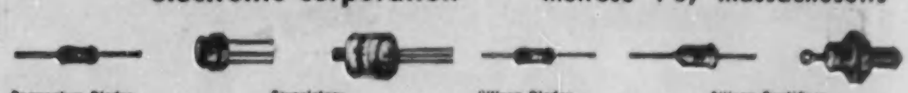


T

RAMBLINGS ON INSTRUMENTATION

Underpriced and Underprofited?

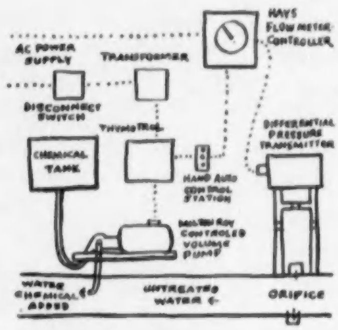
One of our process industry *customers* was talking to us recently about the price situation in the instrument industry, to wit . . . "Why is the instrument industry so underpriced and underprofited? You not only do yourselves a lot of harm—but you hurt those of us who buy the equipment and are identified with instrumentation in our firms. How? When profits of instrument manufacturers are short, research has to be limited. As a result, new ideas and new products are introduced at a decreased rate and we, the users, suffer by not having improved instruments to reduce our costs and improve our efficiency. In addition, higher prices and higher profits for instrument manufacturers would mean that they could pay higher wages to instrument engineers. Thus, all of us identified with instrumentation would be upgraded. Basically, the instrument manufacturer isn't being paid enough for the research, application know-how, and service which stands behind the 'black boxes' which he offers." Anyone agree?

One O_2 Recorder . . . Going Down

Our gas analysis engineers have been impossible to live with since a refinery customer told them the following story: It seems the customer was using a Hays explosion-proof, electronic oxygen analyzer to analyze the oxygen content of the effluent gases of a fluid catalyst regenerator. When the regenerator blew up, the analyzer fell 17 stories (approximately 150 feet) to the ground. Several days later, after the dust had settled, the customer *dug the analyzer out of the ground*, took it over to his lab and checked its performance. The 0-10% range instrument checked within .1 to .2% accuracy. We're selling quite a few explosion-proof analyzers these days.

E Pluribus Unum

Recently we came across a good example of how products manufactured by different companies can be tied together to solve a problem. Calcium build-up on cooling pipes caused overheating of expensive presses which print Better Homes & Gardens, thus, threatening slowdown and serious damage. Our Des Moines representative, Deco Engineering Products, helped engineer the solution (see sketch) involving a Hays electronic mercuryless flow meter, a Milton Roy chemical feed pump, and a GE Thymotrol drive. Result: old calcium build-up eliminated, no new deposits, presses running real cool, man. We can send you the complete story if you're interested.



Move Over, Mantle

A few buttons departed a few vests in our Metrotype Division the other day when an article on data logging in *Industrial & Engineering Chemistry* hit the place. Seems the author listed 21 applications in the process industries, 7 of which were Metrotype. The fellows figure a .333 batting average qualifies them for major league status.

Phil Sprague Jr.

Executive Vice President

WHAT'S NEW

approach were pointed out by Walter, who stated, 'This is the most serious problem before us; to transform the theoretical suggestions derived from cybernetic essays in analysis into practical experimental machinery and situations.'

"In the section on semantic machines, L. N. Korolev of the Academy of Science, U.S.S.R., described methods of machine translation from English to Russian on the BESM computer (see picture below). Some samples were given of scientific text translations performed late in 1955 and early in 1956. A vocabulary of 1,000 words was used, and the text example was Miln's 'Numerical Solutions of Differential Equations'.

"Discussions and essays on 'learning machines' dominated the session on Cybernetics and Life, with the spotlight held by Walter and by Albert Uttley, one of the few physical scientists working in this field. Walter proposed the specifications of a learning machine that 'a noise input gives zero output and the output is a function of the improbability of occurrence of the input signals.' Another interesting paper was presented by Reginald Goldacre, Chester Beatty Research Institute, who showed films demonstrating how feedback could be interrupted in the amoeba to produce violent instability in this organism's mobility.

"The official languages of this Conference were French and English, and no translation was provided. Added to this was the fact that the program was crowded and the chairman rarely kept schedule and inserted unlisted talks. There appeared to be no screening of papers and almost anyone could present his views. Nevertheless, the Conference managed to end on schedule and on a high note of enthusiasm, and plans were made to organize an International Association on Cybernetics.

"In summary, it might be noted that good control engineers must include all relevant factors. Hence as

Pictured above is USSR's Director of Computer Design, S. A. Lebedev, at the console of the BESM machine. BESM's ability to translate English to Russian was described in a paper at Namur.

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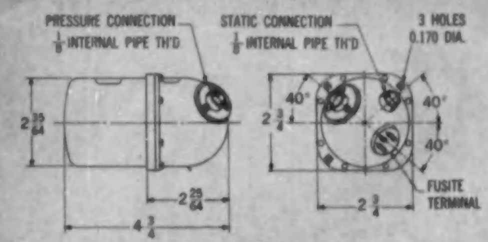

Type B-23471

rotates a synchrotel linearly
with indicated airspeed or
log differential pressure
up to one turn for full range

Kollsman Pressure Sensors are all manufactured to the exacting standards required for high-precision operation in our own computers and flight-control units.

As compared to previous types:

- **1/2 the static volume** — approximately 250 cc
- **2/3 the size** — shown in outline drawing
- **2/3 the weight** — approximately 14 ounces

plus... accuracy within 1/2% of value in most ranges

Write for detailed technical literature. Consult us on your missile or aircraft control problems.

OTHER SYNCHROTEL TRANSMITTERS NOW IN PRODUCTION...

of proven accuracy and reliability ...low, easy maintenance characteristics. Various types available for remote electrical transmission of: *true airspeed, indicated airspeed, absolute pressure, differential pressure, log differential pressure, altitude, Mach number, and pressure ratio.* Single- or two-speed Synchrotel outputs can be furnished on certain units.

AVAILABLE SOON!

New Log Absolute Pressure or Altitude Transmitters with same high-accuracy, low-weight, small-size characteristics as new transmitter featured above.

This new unit will have static volume of only 0.45 cubic inch!

kollsman INSTRUMENT CORPORATION

KOLLSMAN PRODUCES: Flight Instruments • Precision Computers and Components • Engine Instruments • Optical Systems and Components • Navigation Instruments • Precision Flight Controls • Motors and Synchros • Precision Test Instruments for Aviation and Industrial Laboratories

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automatic control systems in business and industry are perfected and better understood, the human element becomes more important and will in the future be included as part of the system. The enthusiasm and shotgun approach of the cybernetics people will undoubtedly add to our useful knowledge. And as their work progresses, the basic problems may be more clearly defined, the activity better coordinated, and progress accelerated.

"A closing word about the three European control conclaves this past spring: Most who attended all three felt that the Conference at Genoa, Italy, was too general; that the papers at Paris were more specific but that general discussion was weak; and that the general discussion encouraged by the chairman was the most stimulating part of the Namur Conference."

Cleveland, June 11-13

The four scenes below give you a quick idea of how seasoned control engineers behaved when they went back to school for a crowded two-weeks' course in process control theory. Bench work in eight specific and eleven optional laboratory experiments was part of a Case Institute schedule that also included 30 lectures by Don Eckman and Irv Lefkowitz. Lecture topics ranged from the "basics" (operational math, block diagrams, Nyquist criteria, etc.) to applicational specifics (liquid systems, thermal systems, surge vessels, etc.). A rigorous course and the first of its kind, this educational conclave when announced (CtE, April 1956, page 26) drew 150 inquiries and 45 definite applications. But "to keep good personal contact between the seven instructors and their pupils", only 22 "students" were accepted. The graduate engineers who took the course were from chemical plants (nine), instrument companies (four), and food, paper, petroleum, glass, and military establishments. They all paid a modest tuition of $275 (including books and banquets) for the 45 hours of lectures, 30 hours of lab, and 30 hours of group discussion. The course *must* have been good: one man planned to stay on at Case and take his PhD.

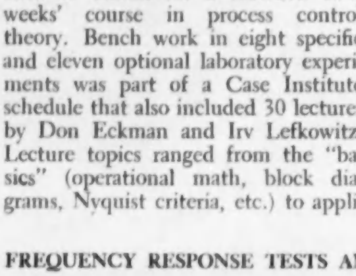
Incidentally, we just received a folder from Case which describes another equally interesting course—this one, on machine control, will be included in the Mechanical Engineering Dept.'s fall '56 program. Dr. Harry Mergler will be the lecturer. His topics (18 of them) range from position and contour control requirements through digital techniques to complete system specification.

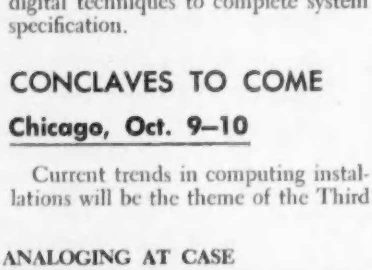
CONCLAVES TO COME

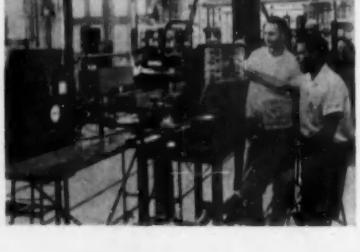
Chicago, Oct. 9–10

Current trends in computing installations will be the theme of the Third

FREQUENCY RESPONSE TESTS AND ANALOGING AT CASE







Annual Computer Applications Symposium, which has lined up 12 speakers from the petroleum, chemical, and aircraft industries; utilities; banking and insurance; heavy and light manufacturing; educational institutions; and the mail-order business. They will cover problems of installation and of revising programs to give effect to changes in procedures; use of computers for problems that cannot be handled by other methods, and modes of approach and type of personnel required. Inquiries concerning the symposium, to be held at the Morrison Hotel, should be sent to J. J. Kowal, Conference Secretary, Armour Research Foundation, Illinois Institute of Technology, 10 W. 35th St., Chicago 16, Ill.

Los Angeles, Oct. 18–19

Growth of interest in the field of managerial sciences will be reflected in the third annual international meeting of The Institute of Management Sciences to be held at the Hotel Statler. The theme of the conference, "Management Sciences—a Progress Report", was announced recently by TIMS President Clifford H. Symonds. Speakers will represent the physical, biological, and social sciences, as well as mathematics and statistics. Management Sciences and Automation, Industrial Applications of Linear Programming, and Management Sciences and Logistics are a few of the session-titles planned. For details contact Crosby M. Kelly, publicity chairman, Litton Industries, Inc., 336 N. Foothill Rd., Beverly Hills, Calif.

Cincinnati, Oct. 22–24

The forthcoming AIEE Conference on Machine Tools at the Sheraton-Gibson Hotel, to be sponsored by the Machine Tool Sub-Committee, will be centered around numerical control of machine tools and will cover many of its aspects: fundamentals, application to various types of machined parts, specific systems in use and under development, static control elements, wiring of automatic machinery, and the latest revisions in machine tool electrical standards. Inspection trips to several firms are planned. For information contact William H. Davis, Allis-Chalmers Mfg. Co., 4453 34th St., Cincinnati 9, Ohio. Registration fee is $3 for AIEE members,

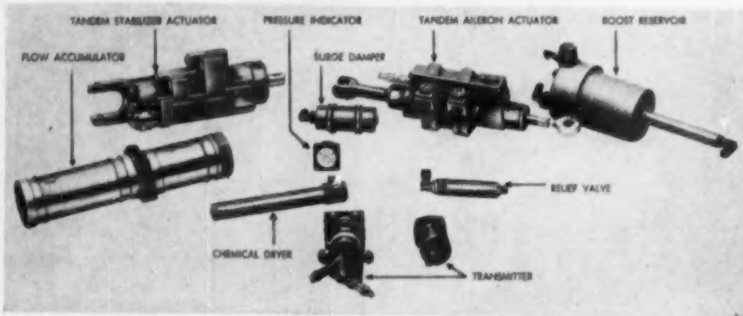
WHAT'S NEW

$5 for nonmembers; make checks payable to "1956 AIEE Conference on Machine Tools".

New York, Nov. 26-30

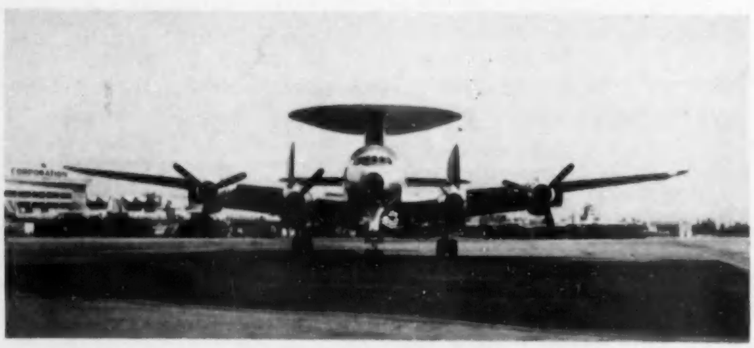
Mayor Bob Wagner of New York took time out before journeying to Chicago and the big Democratic conclave to proclaim Nov. 26-30, 1956, as "Automation Week." By unique coincidence Dick Rimbach's Third International Automation Exposition will be running at the same time in the New York Trade Show Building just north of Penn Station. Besides the large equipment display (running from digital hardware to dust controls), the Exposition this year includes a comprehensive series of clinics and conferences. Clinics cover computers, servomechanisms, process and machine automation, and components, and involve a 90-min lecture and demonstration. The two-day conferences deal with office automation, human engineering, and conveyors for automation. There is a charge of $120 per person (which includes luncheons and dinners). The exhibits are open from 1:00 to 9:00 p.m. daily.

CONTROL IN FLIGHT



Tandem Aircraft Actuator System is Lighter, Safer

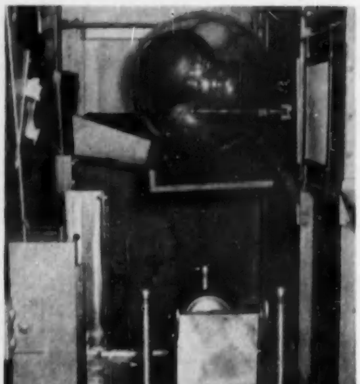
Republic Aviation Corp. is putting into its F-84F Thunderstreak and its RF-84F Thunderflash a simplified tandem hydraulic actuator control system that cuts the ships' weights down by 130 lb and yet is twice as safe as conventional systems. Intended for the primary controls, the system consists of two completely independent mechanisms, each with its own tank and associated plumbing. A dual servo valve and two power-boost cylinders (all in one housing) control the one-piece tail and the ailerons. The system is smaller than standard systems by 50 components, thus accounting for the saving in weight, and either half can be operated without the other, which accounts for the additional safety. Transfer from one half to the other is automatic, and there is no difference in the "feel" of the controls.



Antenna Takes to the Air as Part of DEW System

That isn't a flying saucer riding this airplane, it's a 30-ft discus housing a distance-determining radar antenna. The whole thing, antenna and Navy-

modified Lockheed Superconstellation, forms an experimental early-warning research plant designed to work with sea-going task forces in flying over the ocean patrols as part of the DEW (distant early warning) radar line through Canada. The first tests of the system will be of its aerodynamic characteristics and effect of stability and control, and will be confined to taxiing runs. Flight tests, to follow, will continue the evaluation, coordinating the results with the ground examinations.



Navy Fluoroscope Looks for Flaws in Aircraft Metals

Chance Vought Aircraft, Inc., has the job of determining whether a high-intensity fluoroscope for testing steel and magnesium aircraft castings will hold its own against X-ray inspection. The 'scope, developed by the Naval Ordnance Laboratory for the Bureau of Aeronautics, will judge more than 2,000 castings before any word goes out on it from Vought. Each casting has already been viewed by X-ray, but its conditions is not revealed to the 'scope operator. As the picture shows, smaller castings are placed in plastic globes and held by a cushion of small rubber balloons. The sealed globe is positioned between the 'scope's X-ray tube and the 8-in. viewing screen. Any flaws appear on the screen. The unit will also be tried out on switches, vacuum tubes, fusion weldments, etc., to see if its usefulness can be expanded.

All Around the Business Loop

▶ There's a good possibility that nuclear specialists would disagree on the optimum design for a gas-cooled reactor—simply because no precedent for this kind of power plant exists—but the possibility is just as good that they'd all be in accord on this point: in the field of nucleonics today, there is nothing newer than the concept of the gas-cooled reactor itself.

One company in the U. S., **Sperry Rand's Ford Instrument Co.**, seems to have cornered the work on this type of reactor. Earlier this year Ford took the helm of an AEC study into the possibility of supplementing the conventional power available to Holyoke, Mass., by a $10-million gas-turbine power plant driven by the same gas that cools the plant's reactor. Ford called in **Sanderson & Porter Co.** and the **Gas & Electric Dept.** of the City of Holyoke, but only to take minor roles. It retained for itself the jobs of directing and coordinating all work, designing the reactor, and designing and specifying all nuclear instrumentation and controls. And from the moment the project got under way, Ford was on its own: it was the first time a plan of this sort had left paper.

Instrumentation of this "closed-cycle" idea had been in the works for less than a year when Ford was handed another project by the AEC, this one demanding that the company literally get the reactor off the ground. What the AEC wanted this time was a design for a gas-cooled reactor that would drive an oil tanker, and it wanted it by 1961. Ford complied, and subcontracted with **Nordberg Mfg. Co.** for the ship's propulsion machinery.

Essentially, the new project is an "engineering study" to investigate the economic and technical feasibility of outfitting a 707-ft-long super-tanker of a 38,000-ton dead-weight capacity with a gas-turbine drive. Milton Lowenstein, senior engineer at Ford, tells how his company is going about satisfying both contracts in an article in this issue, page 71. CONTROL ENGINEERING, first to get his report, set the type and let it stand and then waited for declassification by the AEC. The AEC, not too concerned about magazine deadlines, acted none too quickly.

The oil industry, says Ford, is considerably interested in a tanker that would not have to deplete its own cargo to fuel its propulsion plant. And there is a good deal of activity in the front offices of power utility companies and mine operators, too, for the desire for economy is universal

(Continued on page 45)

and the atom-and-gas-turbine concept appears to present the best chance of satisfying this desire, as far as power is concerned.

Not all the problems Ford faces are completely new to the company. One, reactor control, has been an old friend ever since Ford designed and delivered the control-rod drive mechanisms for the Seawolf atomic submarine, the Navy's second nuclear-powered vessel.

▶ **General Electric Co.,** which is filling the biggest civilian order for industrial computers in history (CtE, July '56, p. 42), has established a computer laboratory to speed the work. The project, touched off by **The Bank of America's** request for a battery of Electronic Recording Machines, Accounting, and the laboratory both bear the same name: ERMA. The first ERMA, built by **Stanford Research Institute,** was of a vacuum-tube design. The ones earmarked for the bank will differ in several respects from this prototype, the outstanding difference being transistor construction.

Headquarters for the **ERMA Systems Laboratory** have been established in Menlo Park, Calif. They will serve until permanent arrangements are completed, at which time the 15 scientists and engineers on the project, under Laboratory Manager George Jacobi, are expected to increase to about 50.

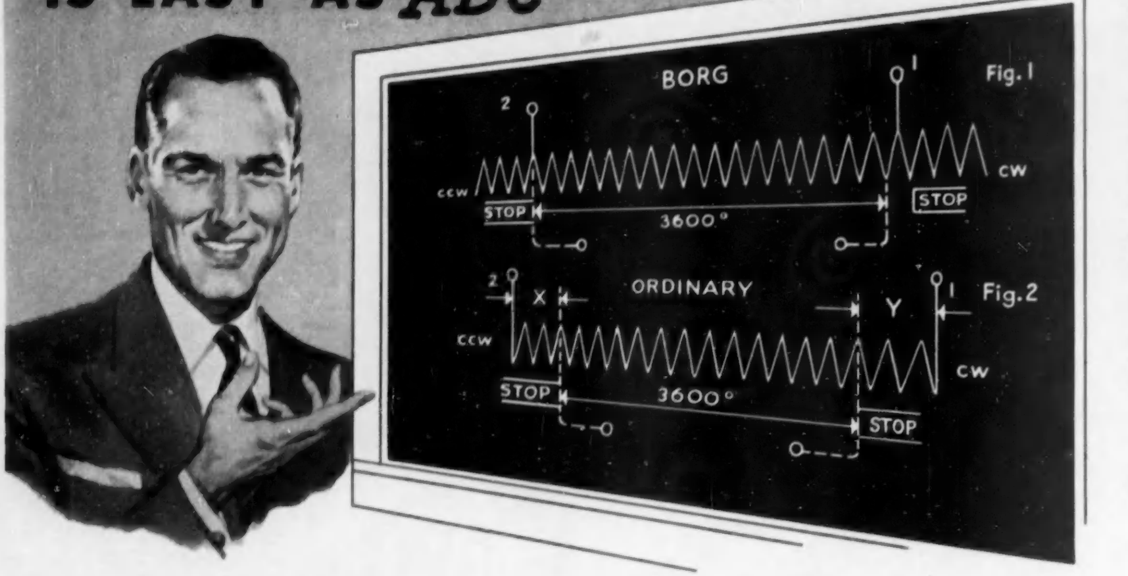
Although right now ERMA is the major concern of the laboratory, her days are numbered. GE planners figure she'll be mature enough to be able to shift for herself in approximately three years, when they'll turn the laboratory over to other activities, including a wide variety of allied electronic computer problems.

Manager Jacobi joined GE's general engineering laboratory staff in 1950. A native of Germany and a graduate of Ecole Nouvelle de Paudex, Switzerland, he was most recently supervisor of engineering for the **General Engineering Laboratory's** analog computer unit.

Another GE man prominent in the ERMA project is Robert R. Johnson, who has done engineering development work in the **Industrial Computer Section,** where ERMA is located. Just recently Johnson was elevated to manager of digital-computer-engineering for the section, in which position he'll organize and

(Business Loop continues on page 154)

TRIMMING ANY BORG MICROPOT IS EASY AS "A·B·C"



Borg Micropots Reduce Assembly Costs With Simplified Trimming of Borg Independent Linearity

All Borg independent linearity MICROPOT Potentiometers may be trimmed at one end only. They will then produce an output voltage within the linearity tolerance of the potentiometer.

BORG MICROPOTS

This is readily illustrated in Figure 1, on the blackboard. The mechanical stops in all Borg MICROPOT Potentiometers with independent linearity, are set beyond the position of each terminal 1 and 2. This allows the contact to travel to the last active turn at either end of the winding. Thus, by positioning the contact at one end point, trimming of that end is not required.

ORDINARY POTENTIOMETERS

Note the mechanical stops in Figure 2. This is an ordinary potentiometer. The mechanical stops are set to prevent the contact from reaching the last active turn, causing "end resistances" X and Y, at either end. Both resistances X and Y must be trimmed to produce voltage outputs within the linearity tolerance of the potentiometer.

TRIMMING COST

The fact that, in Borg MICROPOT Potentiometers, one end can be set up without trimming eliminates the selection of fixed trimming resistors for that end, as well as the time for selection and installation required by ordinary potentiometers.

The maximum portion of the total resistance at the opposite end that would require trimming in Borg MICROPOT Potentiometers is .4%. This is 20% less than in ordinary potentiometers, which substantially reduces the selection of fixed trimming resistors required for use with higher linearity potentiometers.

Lower linearity tolerances may require no trimming whatsoever at either end.

POTENTIOMETER APPLICATIONS

Definitions of potentiometer parameters vary from manufacturer to manufacturer, thus causing misconception to the user. A set of tentative standard definitions has been adapted by RETMA and all Borg MICROPOT Potentiometer tolerances are written for interpretation under these definitions.

The "Trimming Costs" economy in potentiometer application is a typical example of the savings, and in many cases superior performance, achieved through a clear understanding of manufacturing specifications and user requirements.

Write for Complete Engineering Data • CATALOG BED-A56

BORG EQUIPMENT DIVISION
THE GEORGE W. BORG CORPORATION
JANESVILLE, WISCONSIN

Built by Borg

PHILCO® POWER TRANSISTOR

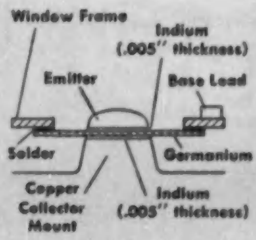
THERMAL DROP 1½°C PER WATT TYPICAL *

The advanced design of Philco Power Transistors gives a new high in reliability. Superior thermal drop is achieved by placing the collector junction in intimate contact with the copper base—and the copper mount is assured maximum dissipator contact by "knee action" of the aluminum mounting clamp. The Philco exclusive cold weld gives freedom from contamination—for *long life!* Long, flexible, insulated leads assure optimum electrical connection in printed circuitry—without disturbing the hermetic seal. Available in production quantities and specifically built for the audio output stage of auto radios, Philco Power Transistors are ideally suited to high power amplifiers, servo-amplifiers, power converters and low-speed switches.

FEATURES

High beta at high currents • 100° C storage temperature * Improved alpha cut-off • Absolute hermetic seal
Low surface leakage currents • Superior thermal drop • Low distortion • Low saturation resistance

Actual Size



Junction Cross Section

Complete Transistor Assembly

Specifications

Power Gain (5W—Class A)	35 db (typical)
D. C. Current Gain ($I_c = -1a$, $V_c = -1.5V$)	40—120
Sat. Voltage ($I_c = 1a$)	0.8V Max.

Maximum Ratings

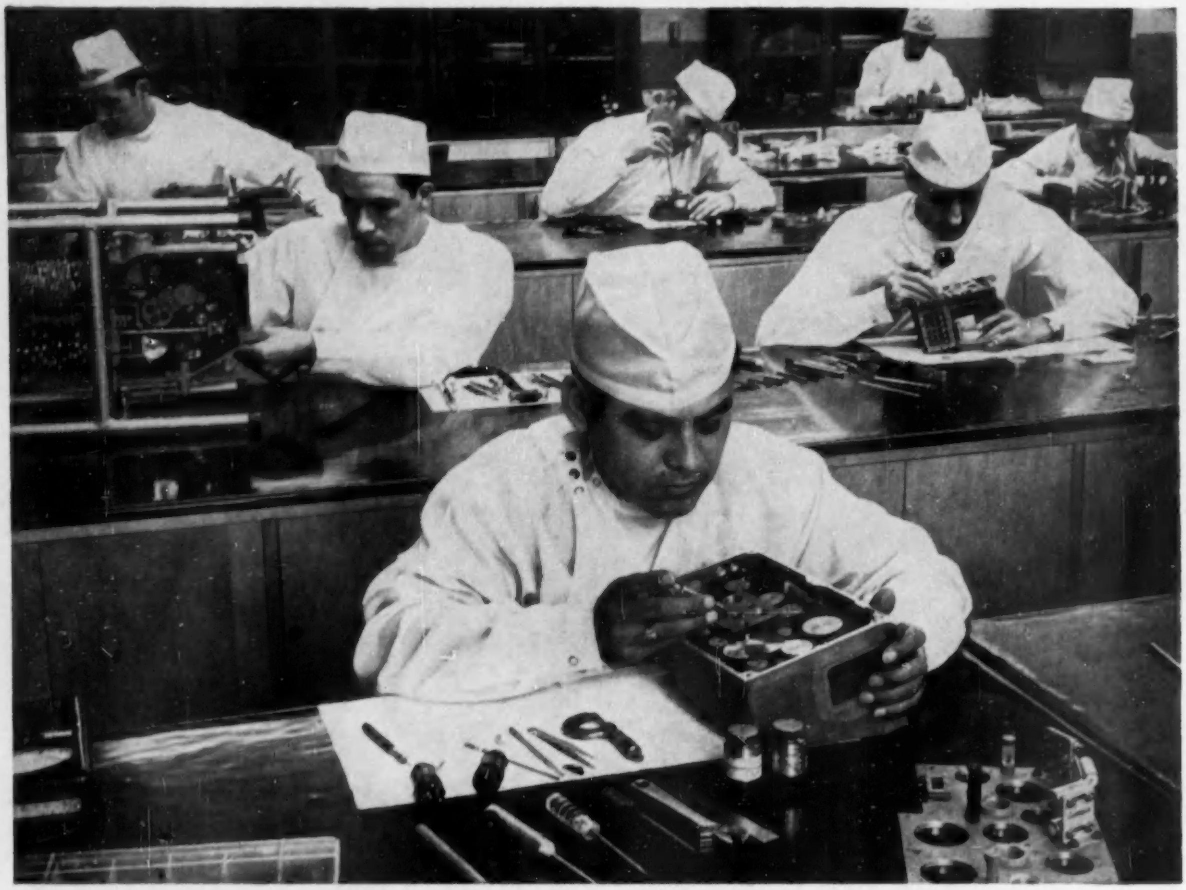
Collector Dissip. @ 75° C Ambient	10W.
Collector Voltage	40V.

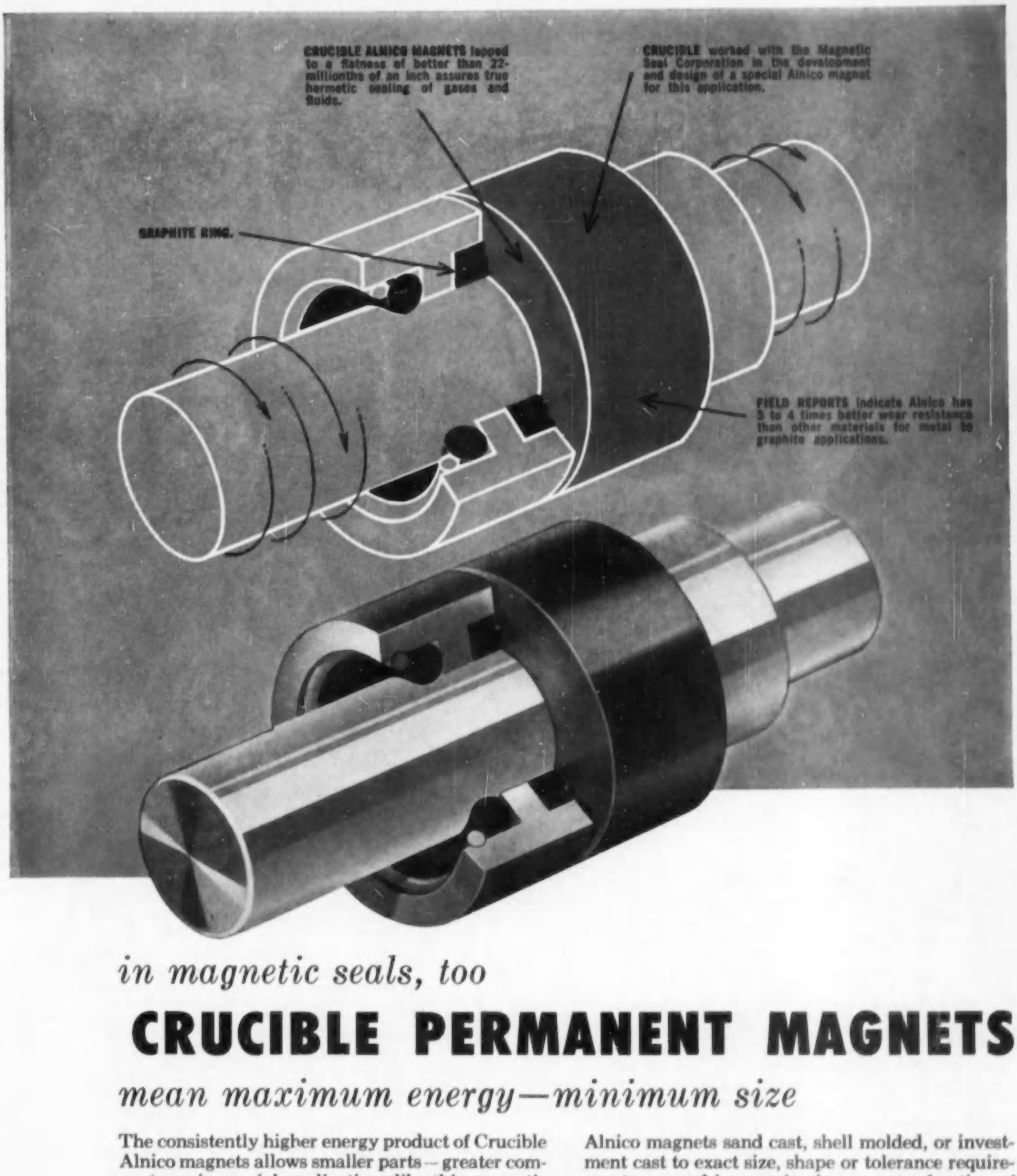
Make Philco your prime source of information for Power Transistor applications.
Write to Dept. CE, Lansdale Tube Company, Lansdale, Pa.

PHILCO CORPORATION

LANSDALE TUBE COMPANY DIVISION

LANSDALE, PENNSYLVANIA





in magnetic seals, too

CRUCIBLE PERMANENT MAGNETS

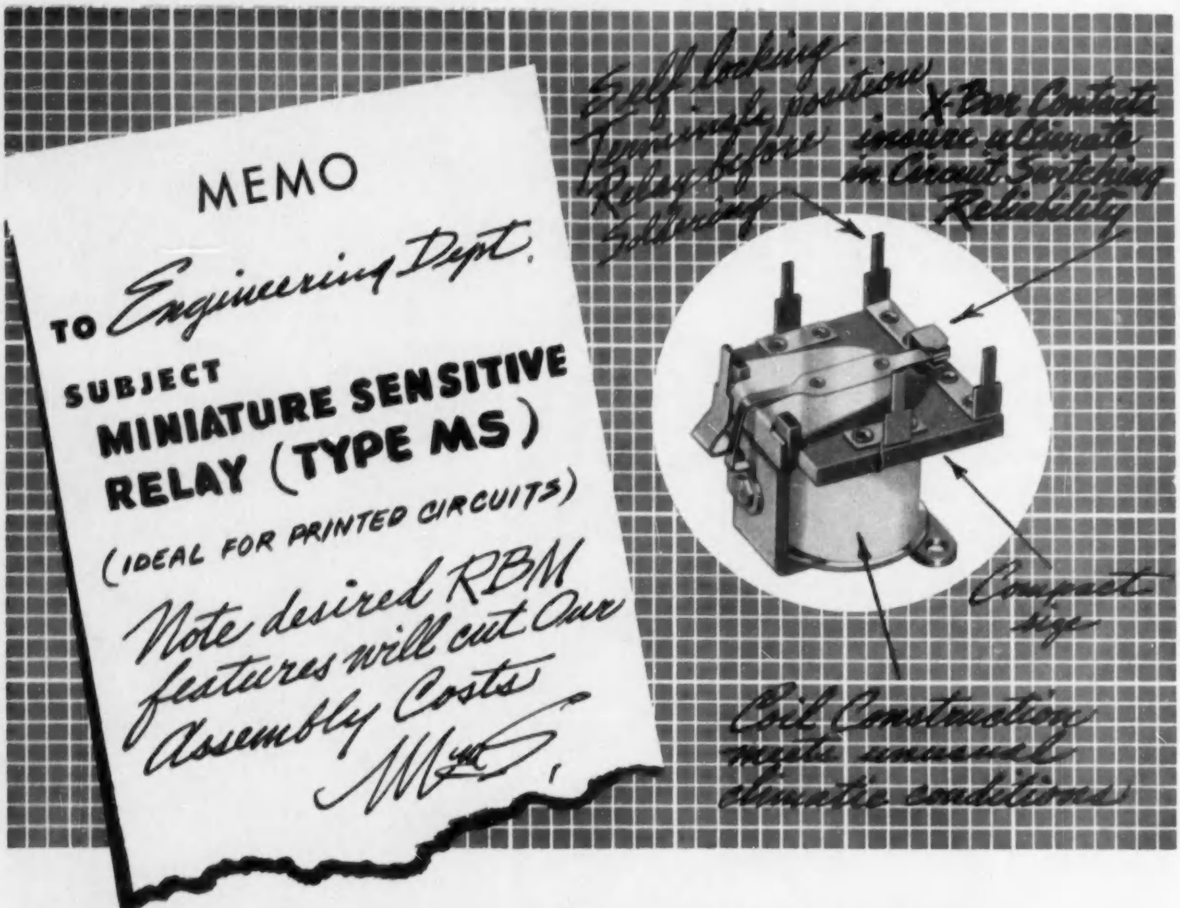
mean maximum energy—minimum size

The consistently higher energy product of Crucible Alnico magnets allows smaller parts — greater compactness in special applications like this magnetic shaft seal. What's more, the superior corrosion and wear resistance of Crucible Alnico insures far greater service life.

You can regularly get Crucible permanent Alnico magnets sand cast, shell molded, or investment cast to exact size, shape or tolerance requirements . . . and in any size from a mere fraction of an ounce to hundreds of pounds. *Crucible Steel Company of America, The Oliver Building, Mellon Square, Pittsburgh 22, Pa.*

CRUCIBLE first name in special purpose steels

Crucible Steel Company of America



Construction—Printed circuit terminals are designed with snap-in feature which holds relay in printed circuit board without lugging prior to solder dip.

Other versions of MS relay available with standard solder type terminals and insulating base, where required. Also with 4 N.O. isolated circuits having common make.

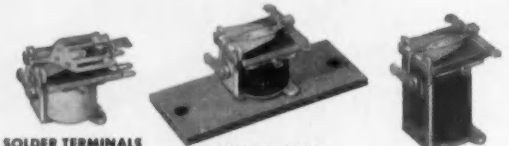
While not yet in production, extra-sensitive version has been developed. Maximum coil resistance 18,000 ohms, nominal sensitivity .030 watt, maximum sensitivity .020 watt, overall height 1-9/16". All other details same as standard MS relay.

Application—Type MS is an ideal relay for any application requiring a compact, highly reliable single pole D. C. device, where a low cost solution is required because of volume usage and competitive problems.

The fact that industry has already used over a million units of this design is your assurance that the R-B-M Type MS relay will meet your most exacting requirements.

Contacts used in Type MS are of the cross bar type, which offer the ultimate in reliability throughout the life of the relay. Molded bobbin design has eliminated coil failure on sensitive applications under severe climatic conditions.

OTHER VERSIONS



SOLDER TERMINALS 4 isolated circuits with common make contact.
INSULATED BASE Solder terminals mounted on insulating base.
EXTRA SENSITIVE VERSION

ENGINEERING DATA	
Specifications	Miniature Sensitive Relay Type MS
Contact Form	S. P. D. T.
Contact Rating	1 amp. 32 V.D.C. non-inductive
Coil Resistance	Up to 10,000 ohms
Nominal Sensitivity (Coil Input)	.060 Watt
Maximum Sensitivity	.040 Watt
Approx. Dimensions	1⅛ x 1⅙ x 1½"

OTHER PRODUCTS

CORD SETS
WIRE HARNESSES
MAGNET WIRE

Send for Descriptive Bulletin MS-1

RBM DIVISION

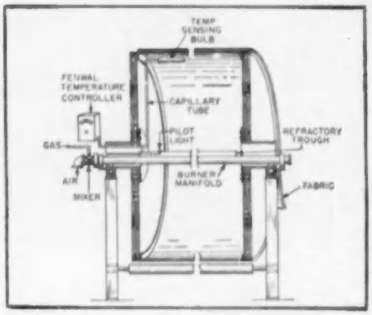
ESSEX WIRE CORPORATION, *Logansport, Indiana*

Controlling A Radiant-Heat Drying Drum

No. 3 in a series — *Showing the Broad Application Range of Fenwal Controls*

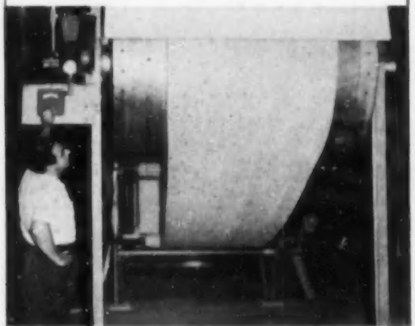
This high-temperature, radiant-heated drying drum is used for drying printed fabrics or for heat-setting synthetic coatings onto fabrics. Particularly interesting is the way in which it combines a Fenwal unit and quick cooling features to secure the close temperature control necessary to prevent scorching the fabric in case of shut-downs.

The drum is usually operated at a surface temperature of 350° to 450°F, but can maintain temperatures up to 700°F, as required. The revolving drum surface is heated by a combination of infra-red rays and convection from a refractory trough heated to incandescence (about 2400°F) by a gas-air manifold burner.



Drum temperature is controlled by a Fenwal Series 540 Indicating Temperature Controller. As shown in the diagram, this is connected by a capillary tube to the temperature-sensing bulb, located close to the interior surface of the drum. The trough and manifold are stationary along the axis of the drum. Flame is played along the surface of the trough by a series of jet nozzles, burning a mixture of air and natural or manufactured gas. To aid in preventing scorching the product, materials used for the drum and heater system are of lowest practical heat capacity. The drum surface is of 16-gauge steel, which assures a low heat content.

Also, the combustion air supply doubles as a coolant for the drum. The air stream is not tied in with the temperature control system and continues to flow after the gas is shut off. Thus, it quickly cools the heater trough and blows the heated air out of the drum. This, plus the low heat capacity of the drum surface, provides the required safeguard against scorching the product during sudden shut-downs.



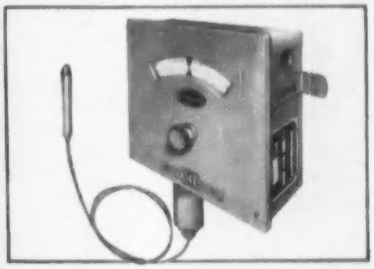
PRECISE TEMPERATURE CONTROL, provided by a Fenwal Series 540 Temperature Indicating Controller (shown at left) is one of the advantages enabling this huge drying drum to set new records for efficiency. In one installation, three 60" diameter drums of this type are drying the same yardage as 20 previously used steam-dryers.

Control Within ¼ of 1%

When the operator sets this Fenwal Series 540 Controller to the required processing temperature, he knows that temperature will be maintained — on the button! Heat input is controlled by the Fenwal unit, actuating a solenoid valve in the supply line. The gas, maintained at atmospheric pressure by a diaphragm regulator, is drawn into a proportioning mixer valve under negative pressure created by the air stream. The air supply, maintained at approximately one psi, reaches the mixer through a separate supply line.

With the Series 540 Control on guard over the heating system, the manufacturer of this advanced drying equipment states that the temperature of the drum surface is maintained within ± one-quarter per cent of the controller scale — outstanding performance for processing equipment of this type.

A Versatile Instrument



The Series 540 Controller is fully adjustable between 100°F and 700°F. Temperature differential is adjustable between 1% and 4% of scale temperature ranges by internal adjustment of pilot contacts. Uniform sensitivity and close accuracy throughout its range are characteristic, making it an ideal temperature indicating controller for kilns, ovens, liquid baths, baking ovens, packaging machinery and general industrial processing.

For Your Own Applications

Investigate the many different types of Fenwal temperature control and detection devices. Besides the Series 540 described here, these include standard THERMOSWITCH® units, Midgets, Miniatures, etc. Send the coupon for new Catalog No. 500. Remember that Fenwal's engineering staff is always ready to help you solve any temperature control problem.

FENWAL INCORPORATED
5910 Pleasant Street
Ashland, Mass.

Please send me your Catalog No. 500. Our specific problem is:.............................

....

....

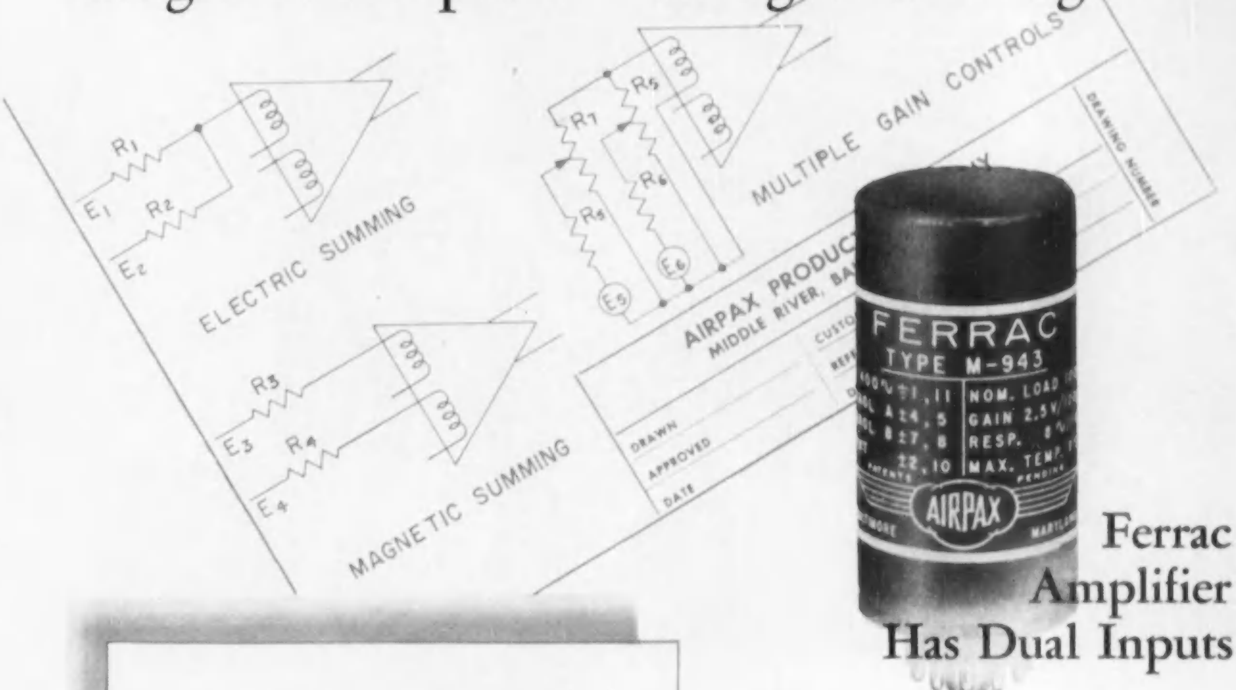
Name.............. *Title*..........

Address.........................

City.......... *Zone*.. *State*.......

Fenwal CONTROLS TEMPERATURES . . . PRECISELY

Magnetic Amplifier for Signal Mixing



Ferrac Amplifier Has Dual Inputs

FERRAC AMPLIFIERS

INPUT: Two fully isolated control coils. DC polarity reversible.

OUTPUT: Unfiltered DC, polarity reversible linear ± 7.5 DC volts into a 1000 ohm load.

GAIN: Typical gain gradients of Ferrac amplifier are 2.5 volts output per 100 μa input, 0.5 V/100 μa, and 10 V/100 μa. Under standard conditions, the gain of any Ferrac amplifier is within ± 1 db of its nominal value and within ± 2 db under environmental conditions.

POWER REQUIREMENT: 115 volts at 400 CPS ± 10% in voltage or frequency; approximately 1.5 watts for standby and 2.5 watts at maximum output.

ENVIRONMENT: —55 C to +85 C operating, withstands 10 G vibration from 10 to 55 CPS in any position for 1 hour and 30 G shock of 11 ± 1 millisecond duration in any position, is hermetically sealed.

Here is the magnetic amplifier you have been looking for. Its characteristics make it ideal for computing functions in analog controls. Basic to such computation is signal mixing or summing.

The schematic shows how a Ferrac amplifier can be used to sum several signals. For simplicity, the diagrams show two signals being mixed; more signals can be summed if necessary.

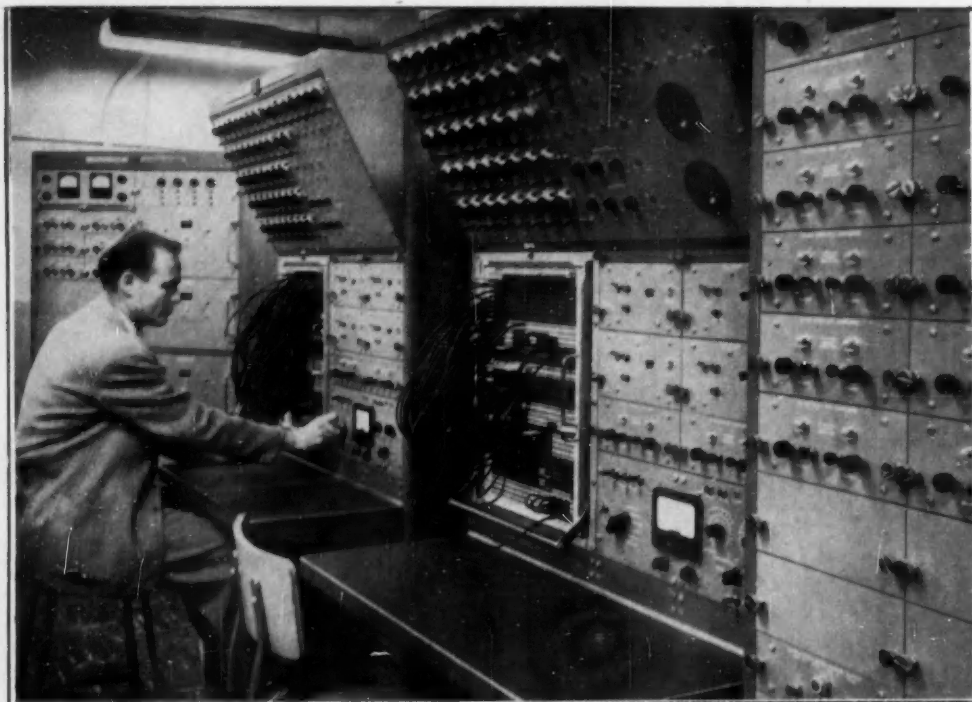
Either electric summing or magnetic summing can be used, or both can be used in combination. Electric summing mixes the signals through summing resistors connected to the amplifier input, one resistor for each signal. Magnetic summing mixes the signals through summing control coils in the magnetic amplifier, one control coil for each signal.

Magnetic summing is particularly flexible. The signals do not need a common ground; they can be isolated from each other. Multiplying coefficients are provided by resistors in series with the control coils of the amplifier; these resistors can be made variable to change the coefficients in accordance with changing control condition.

Would you like to know more about this versatile Ferrac magnetic amplifier? Simply write us.

AIRPAX
DESIGNERS ENGINEERS

MIDDLE RIVER BALTIMORE 20, MD.



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North American Aviation, Inc.

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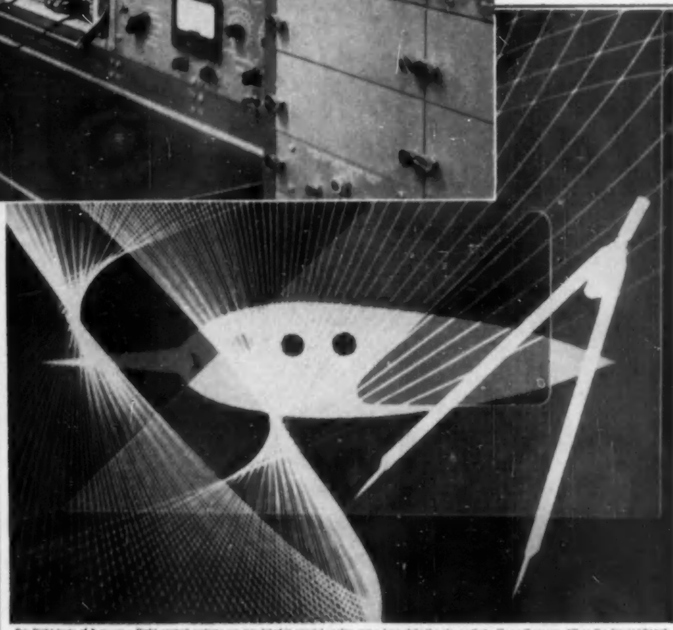

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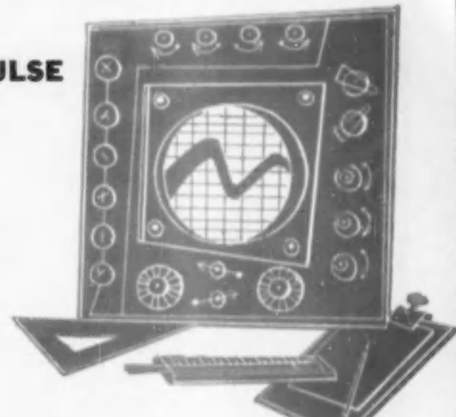


What Do the Annual Reports Say?

In the past several months our incoming mail has been carrying annual reports from companies in and around the control field. Many of these brochures are first efforts of long-established companies—a growing sign of a maturing among the suppliers of control products. But the number published is surprisingly small, considering the many million-dollar firms in the business. The 20 annual reports analyzed below are an interesting sampling of the industry. To help the analysis we've made some arbitrary groupings based on the area of control of each firm as suggested by its report. Let's first look at the industrially oriented:

New faces of 1955

Industrially Oriented	Sales 1955	Sales 1954	Comments
Consolidated Electrodynamics Corp.	$17,124,429	$15,644,520	While background is military, stress is on systems work in process field; part of income comes from high vacuum equipment
Electronics Corp. of America	11,302,456	5,590,209	Primarily industrial; '55 saw new sales for explosion-safety systems for military, new items for business data processing
*Fischer & Porter Company	8,697,000	8,138,000	Figures on '56 fiscal year show increase in net shipments to $11 million, gains in data logging equipment, flowmeter sales
General Precision Equipment Corp.	133,337,819	123,332,634	While a good share of income is from military, divisions of this firm focus on industrial control, some consumer products
Minneapolis-Honeywell Regulator Co.	244,482,068	229,401,837	Defense orders decreased in '55, big gains were in commercial heating and air conditioning control, industrial instrumentation
**Perkin-Elmer Corp.	6,742,633	6,810,055	Almost $4 million in sales of commercial instruments, remainder in contracts and optical products (i.e., new TV zoom lens)

*Fiscal year ending April 30 **Fiscal year ending July 31

On first glance the sales growth of companies who cater to—or stress their interest in—the industrial control field is rather modest. Only one (Electronics Corp.) showed startling progress, and this may be due to this company's successful marketing of a new military control system. However, when you look into past annual gains by most of these firms—particularly the big ones—you'll spot amazing growth during the Korean conflict

Modest growth is deceptive

period. That most continue to gain today is a healthy sign of consolidation and a still-growing market.

Let's now look at a group of companies whose annual reports frankly admit a major income from military-type contracts:

Military-Aircraft Oriented	Sales 1955	Sales 1954	Comments
American Bosch Arma Corp.	$73,805,025	$74,416,211	Large income from electrical equipment for automotive field; Arma Div. backlog in military contracts $170 million
*Coleman Engineering Co., Inc.	2,546,643	1,078,522	Over 80% of sales come from cost-plus-fixed-fee contracts, but some products (i.e., digitizers) have industrial potential
G. M. Giannini & Co., Inc.	6,400,000	4,308,467	Produces mainly transducers and controls for aircraft and guided missiles; created a new Controls Div. early in '56
Lear, Inc.	54,600,273	54,435,637	Sells primarily flight control and autopilot systems, but new components (i.e., gyros, actuators) also offered in '55
**Litton Industries, Inc.	8,774,273	2,980,051	Main income is from the military, but firm is pushing a new analog computer to industry and has enlarged its component line
*Topp Industries, Inc.	2,115,734	1,667,276	In '55 this firm entered consumer field (awnings, patios) and brought out a new machine-tool-control transducer
Servomechanisms, Inc.	12,412,756	12,509,024	As of March '56, this firm's contract backlog was $21 million; it reports a growing income in machinery control items

*Fiscal year ending April 30 **Fiscal year ending July 31

In this group the growth picture is much less clear. Some firms shot ahead to double, even triple sales in '55. Others held static and even slipped slightly. There is only one visible correlation: the smaller firms are the ones with the most growth. This may be due to the government's decision in the past few years to spread its defense contracts throughout industry. A half-million dollar order which may be "modest" to a big firm can give an epic boost to a little company.

Youngsters show the most growth

And now on to another somewhat special group of firms—those that sell electronic components:

Electronics Oriented	Sales 1955	Sales 1954	Comments
Magnetics, Inc.	$1,390,677*	$986,217**	Big gain in sales of magnetic cores for digital computers, magnetic-amplifier line; doubled sales expected in '56
#Raytheon Manufacturing Co.	183,304,693	177,099,790	Defense contracts backlog $96 million in May '55, but component sales to industry, consumer products also increasing
Texas Instruments, Inc.	28,684,653	24,387,334	Firm is expanding its line of "basic electronic building blocks"; part of income derived from geophysical instruments

*Sales reported are for first six months '56.
**Sales reported are for first six months '55.
#Fiscal year ending May 31.

This fairly uniform growth substantiates the fact that there is opportunity for newcomers to the field. Magnetics, Inc., for example, is only three years old and is already making reports like a multi-million dollar corporation. It is interesting to note that all three companies are leaders in solid-state devices, and the reports indicate that much of the vigor in 1955 was due to wide industry acceptance of such items.

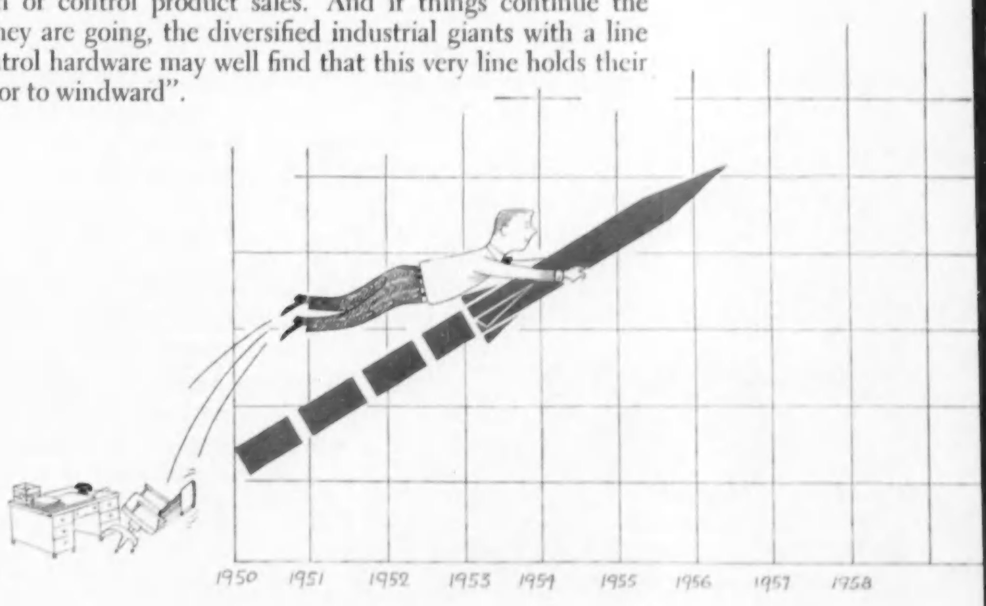
Solid-state stimulation

Some of the incoming reports were from the giants in industry, those that consider control simply a component part of their market. Let's see how these diversified companies fared:

Broadly Diversified Companies	Sales 1955	Sales 1954	Comments
Borg-Warner Corp.	$552,192,430	$380,317,341	This firm has 37 divisions, many of which make control loop items, but only three of them fairly distinctly in the control field
Baldwin-Lima-Hamilton Corp.	160,300,000	155,200,000	The Electronics and Instrumentation Div. is one of seven; a new 102,000-sq-ft plant is being readied in Waltham, Mass.
Westinghouse Electric Corp.	1,440,976,985	1,636,184,253	Strikes late in '55 curbed sales; military orders shipped in '55 totaled $200 million; "Cypak" systems introduced in '55
Dynamics Corp. of America	41,894,958	36,440,014	Makes mainly consumer items (appliances, TV equipment), but Reeves Div. is adding machine and RR control to its military work

With the notable exception of Borg-Warner (which boosted appliance sales by 73 percent in '55) the diversified firms show no unique sales advantages over firms of similar size which specialize almost exclusively in control. Diversification, of course, provides the needed buffer when and if the control division "slacks off". But in all years covered, with the possible exception of a "sticky" '48, there has been no sign of a decline in the growth of control product sales. And if things continue the way they are going, the diversified industrial giants with a line of control hardware may well find that this very line holds their "anchor to windward".

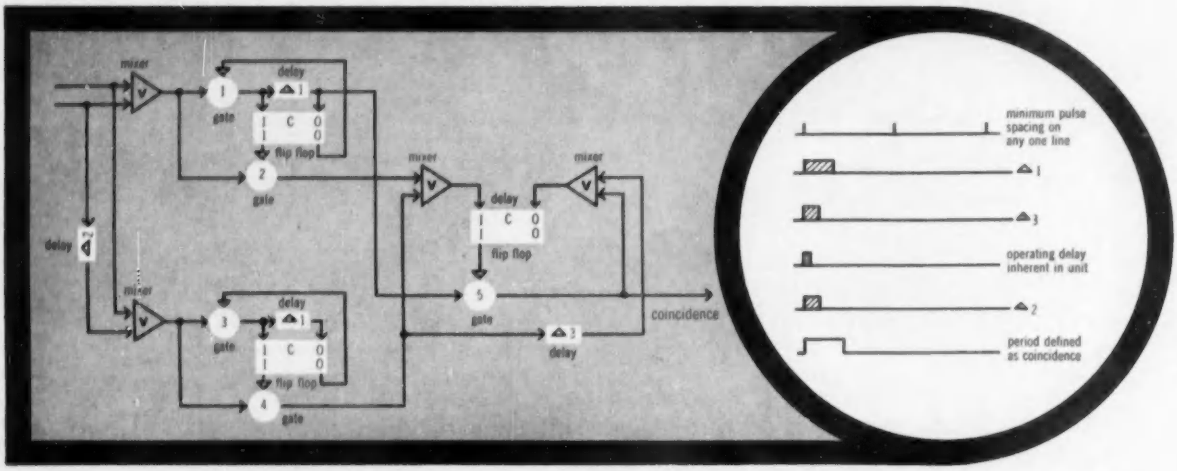
An anchor to windward



solving logical problems with Burroughs pulse control systems

detecting coincidence between two random trains of pulses

The diagram below shows a quick, easy logical method of detecting coincidence between random pulses on two different lines—pulses which might occur simultaneously, well within the switching time of even the fastest units. In this case, the systems approach proved to be more feasible than increasing the precision of the components.



Logical problems such as this one still tie up most of today's engineers . . . making them design breadboard equipment to prove out their solutions . . . relegating their creativeness to secondary projects. Burroughs Pulse Control Systems cut through these time-consuming operations by giving the engineer a quick, logical method for checking his results.

Each unit in the Burroughs System represents a basic logical function. The engineer has only to hook up a number of these units to correspond with his block diagram, and the solution is ready for proof. Intermediate breadboarding is completely eliminated . . . his concept is proved or disproved quickly . . . and he is free to concentrate on the end result.

You can give your engineers this creative edge by letting Burroughs Pulse Control Systems take over the burden of proof. A Burroughs engineer will be glad to call on you—at your convenience—and show you how to save hours of engineering time and production headaches. Or, write for Bulletin 236.

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Control
ENGINEERING

OCTOBER 1956

Prove Each Step

Bold new approaches to measurement and control are vital to the contrc field if it is to continue to grow at its current rate, a rate so dramatic that the field has become, in the words of the business press, "the technological revolution" behind our expanding industrial economy. Creative approaches should be encouraged, for with them the control engineer may bypass technical and economic roadblocks. But the magnitude and complexity of the imagineered control systems must not be so great that the systems cannot be broken down into pieces that individuals and small teams can prove out.

Our September '56 issue, designed to demonstrate the procedures of control systems engineering, made it clear that the practitioner does not solve a complete systems problem by some mystic clairvoyance that gives him all the answers in one lump. He methodically separates the interlocking branches of a system into subsidiaries of such character and size that his team can grasp their requirements and cope with them. Then the team takes each subsystem along a three-legged course of specification, synthesis, and evaluation, firmly proving its performance internally and in relation to other subsystems.

Turn to page 24 of the current issue for a case study of the method at work. It is a report on a system for centralized real-time computation of production plant yields. It strongly hints that many plants making the same product but with different production schedules, manufacturing and transportation incremental costs, available capacities, and processing dynamics, may someday feed information to a central computer. Should this happen, the computer may determine, by calculation, the optimum plant at the time and assign increased production to it. The idea is not new; the application and its inherent problems are. The case teaches a number of important lessons that we will cover in November. Most noteworthy from a professional viewpoint are these:

- The project required a team. It was composed of an instrument engineer familiar with plant application problems, an engineer competent in dynamic analysis, and a digital computer specialist.
- The team took a limited, but bold step, and proved the strengths and weaknesses of the step.

Now the team knows what the next steps are toward the centralized control of a production business. It is a convincing lesson in technique.

THE EDITORS

To meet the increasing demand for miniaturization, Fairchild's line of sine-cosine potentiometers has been expanded and now includes 3", 2" and 1⅛" diameter sizes. Development of these sizes resulted from Fairchild's continuous and extensive research to provide users with the practical balance between size and functional conformity to best meet their individual needs. As an example, an entirely new winding technique has been developed by Fairchild which assures greater accuracy and reliability with longer life.

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No matter what factors govern your choice of precision potentiometers, you'll find the answer in Fairchild's complete line. Write Dept. 140-71C, Fairchild Controls Corporation, Components Division, 225 Park Avenue, Hicksville, Long Island, New York.

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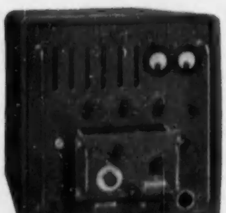
Measures weight, pressure, temperature, acceleration*
Direct numerical readings 1 cps to 120 KC
High accuracy, simple operation, compact, rugged

-*hp*- 521A—$475.00

New -*hp*- 521A is designed to be the most useful, accurate low cost industrial counter ever offered. It measures frequency, speed, rpm, rps, and counts random events within a selected time interval. With transducers, it measures weight, pressure, temperature, acceleration and other phenomena which can be converted to frequency. It is direct reading in cps, rpm or rps, and can be used readily by non-technical personnel. Period of count is 0.1 or 1 second; display time can be varied.

The 50/60 cycle power circuit is used as the time base; or, for greater accuracy, a plug-in crystal controlled time base is available at extra cost. There are accessory power supplies of —150 v dc, +300 v dc and 6.3 v ac. Connections are also supplied for photocells and an external 60 cycle standard. Lightweight, compact, sturdy; particularly useful with -*hp*- Optical Tachometer Pickups and Tachometer Generators. -*hp*- 521A, $475.00 (with plug-in crystal time base, $575.00).

Other versatile -*hp*- Counters

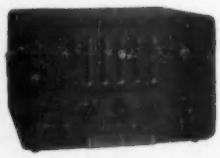


-*hp*- 524B Electronic Counter with 525/526 series Plug-Ins. Revolutionary all-purpose, direct-reading counter. Buy basic counter, plug-ins giving measuring coverage you need now. Later add other inexpensive plug-ins to double, triple counter's usefulness. Basic counter range: Frequency 10 cps to 10 MC, period 0 cps to 10 KC, stability 1/1,000,000. -*hp*- 524B, $2,150.00^Δ^.

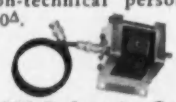
-*hp*- 525A/B Frequency Converters extend 524B's range to 100 or 220 MC, increase video sensitivity. -*hp*- 525A/B, $250.00.

-*hp*- 526A Video Amplifier increases counter's sensitivity to 10 mv, 10 cps to 10 MC. $150.00.

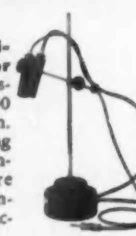
-*hp*- 526B Time Interval Unit permits counter to measure interval 1 μsec to 100 days with accuracy of 0.1 μsec, ±0.001%. $175.00.



-*hp*- 522B Electronic Counter. Compact, moderate price; frequency, period or time measurements. 10 cps to 100 KC. Reads direct in cps, KC, seconds, milliseconds. Automatic count reset, repetitive action. Stability 5/1,000,000, display length variable. Easily used by non-technical personnel. $915.00^Δ^.



-*hp*- 508A Tachometer Generators. Use with electronic counters, frequency meters to measure directly 15 to 40,000 rpm. Produces 60 cycle output frequency per revolution; (-*hp*- 508B produces 100 cycles) -*hp*- 508A or 508B, $100.00.



-*hp*- 506A Optical Tachometer Pickup. For measuring rotation 300 to 300,000 rpm. Ideal for moving parts of small energy or where mechanical connection is impractical. $100.00.

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Automatic Programming of Numerically-Controlled Machine Tools

ARNOLD SIEGEL, Digital Computer Lab., Massachusetts Institute of Technology

THE GIST: Programming a numerically-controlled machine tool is a long and expensive task involving transfer of detailed blueprint information into a form acceptable to a numerical director. To realize the full potential of numerical control, some way must be found to simplify this procedure. The use of a digital computer, which can handle the simple repetitive calculations that consume so much of the programmer's time, seems a natural step. Experimental work carried on at MIT has shown that Whirlwind I (a general-purpose digital computer) can be programmed to accept simple information directly from engineering drawings (such as point coordinates, line directions and terminal points, circle radii and center location, etc.), and prepare a tape for input to the numerical director of the MIT numerically-controlled milling machine. This so reduces the machine-tool programming task that a skilled procedures man can develop the required input information for Whirlwind I in a relatively short time. The computer routine described here will only handle the machining of plane shapes, but the extension to three-dimensional machining is straightforward. Other general-purpose computers can be programmed in the same way as Whirlwind I, or special-purpose, fixed-program computers can be developed for the job. At least two commercially-available numerical control systems already use a special-purpose digital computer.

Programming for numerical control divides into two basic stages[1]. The first stage requires familiarity with machine tools and metal-cutting techniques because it is necessary to determine how each piece can best be cut, how to hold the work, what jigs and how many setups are required, and what spindle speeds, cutter shapes, and feed rates must be specified. In this stage of planning, in which initial decisions must be made by trained and experienced personnel, empirical knowledge, experience, and judgment are the determining factors.

The second stage in machine programming is the computation of the actual machine commands as they will be transmitted to the numerical director. The earlier decisions affect the form of these instruc-

AS SIMPLE AS THIS

At left—A typical program tape for a simple workpiece, together with the typewritten copy obtained in preparing tape on Flexowriter. The punched tape at right is in the special binary code of the numerically-controlled milling machine, prepared from the Flexowriter tape by Whirlwind I.

tions; thus the programmer must have the results of the preliminary analysis at his disposal. However, the second stage is primarily routine. It consists of dividing the desired cutter path into elementary machine motions and computing the numerical values associated with each elementary command. Many numerically-controlled tools machine a series of straight lines, the number and length of the straight lines depending on the degree of curvature of the surface being cut and the allowable machining tolerance. This means the programmer must divide the cutter-center locus (since it is cutter-center location that is controlled, rather than the actual cutting point on the contour, the programmer must determine the cutter-center locus that will yield the correct machined contour with a certain size and shape of tool) into a multiplicity of straight line segments, and in turn determine the two- or three-dimensional coordinates of each end of each segment, no matter how small. This information, plus certain items from the first stage, are transferred to a storage medium that can be read by the numerical director. The director converts these data, in the proper positional and time relationships to yield the desired contour, into input signals for the machine tool's power servomechanisms. Most of the programming time is consumed in determining the cutter-center locus and specifying the straight-line segments. It is here that a digital computer can lighten the burden and reduce the expense of programming.

What the computer does

The computer must be able to accept relatively simple input data describing the piece that is to be machined, process them, and produce blocks of information defining sequential machining steps, directions of cut, feed rates, etc., in a language and physical form that can preferably be fed directly to the numerical director.

When a general-purpose computer, such as Whirlwind I, is used, a routine or program must be developed that will cause the computer to properly manipulate the input data to yield the desired output information. Since this same routine is used each time the same machine tool is automatically programmed by the same digital computer, it should be capable of handling the vast majority of workpiece shapes that are to be produced under numerical control on this particular tool (or an identical tool), and should be as simple and straightforward as possible. To meet these specifications, the routine should be written by experienced program coders. A carefully-coded routine used by personnel unfamiliar with computer coding can reduce mistakes, and provides many mistake-detecting features. A routine can be stored on punched cards or punched or magnetic tape and read into the computer each time a new workpiece is to be programmed.

The physical form and language of the computer output should match that of the numerical director input, even if the computer must translate from its own code to an entirely different code for the machine tool. This avoids further processing after the information has been obtained.

The fact that the computer must usually be communicated with in a complicated language (or instruction code) is of no concern to the procedures man programming a workpiece. The information punched on the input cards or tape is read and interpreted by the special processing routine for programming the numerical director, not by the computer's usual input routines. The only conditions with respect to the input language, therefore, are that the desired input symbols can be recorded and that the instructions for translating the selected language into computer language must have been included in the processing routine. The high speed of modern computers means that the time expended in translating from a simple language into a complex one is negligible. It takes much longer and is many times more difficult for a human being to produce a correct routine in the computer's language.

The input language

Unfortunately, no input device is available (or envisioned in the near future) that would enable a computer to read a blueprint directly. Therefore, some transcription is necessary. Whirlwind I accepts punched paper tape produced by a Flexowriter tape-perforating machine, and this medium was chosen for the computer input. The input language consists of "statements", some in plain English and some in semi-mathematical notation, that describe what the programmer sees on the blueprint and what he wants the machine tool to do. The statements, of course, use only those symbols that are available on the Flexowriter keyboard.

For simplicity, the first version of the processing routine has been limited to points, circles, and straight lines in a plane. Motion of the cutter in the third dimension can be handled, but in a less flexible way than plane motions. Curves and surfaces specified by mathematical equations or by arbitrary sets of coordinates have been excluded entirely, although there is nothing inherent in the input language or processing routine that prohibits the extension of this technique to handle these cases. (Actually one commercially-available system using a special-purpose computer—by Ferranti, Ltd.—is programmed to handle any conic section. Ed.) Since most engineering drawings consist primarily of straight lines and circular arcs, however, this simplified routine will handle most situations. (Curves other than circular arcs can be included by dividing the contour into straight-line segments, just as though the numerical director was being programmed directly. The complexity of the routine depends on the types of workpieces being machined.)

The input language consists of three basic types of statements. The first defines the points, lines, and

TABLE I **DEFINITIONS**

POINTS		
	By coordinates	p1 = −2.738, 10.372
	As the intersection of two lines	p2 = s23|s7
	As the intersection of a line and a circle	p3 = Ns2|c2 p4 = Fs3|c6
	As the intersection of two circles	p5 = Nc3|c5 p6 = Fc2|c7
	On a circle, at a given angle with the positive x-axis	p7 = c2|83.074°
LINES		
	By two points	s1 = p2|p9
	Through a point and tangent to a circle	s2 = p3|Tc2 s3 = p7|Ac9 s4 = Tc7|p4 s5 = Ac6|p5
	Tangent to two circles	s6 = Ac2|Ac3 s7 = Tc4|Ac5 s8 = Ac2|Tc7 s9 = Tc12|Tc6
	Through a point, at a given angle with the positive x-axis	s10 = p7|−73.215°
CIRCLES		
	By center and radius	c1 = p2|2.7405
	Center, tangent to another circle	c2 = p2|Tc4 c3 = p5|Ac7
	Center, tangent to a line	c4 = p5|s2

circles that make up the piece to be machined. These *definitions* may be either absolute (numerical) or implicit (in terms of other geometrical figures that have already been defined). The second type specifies the sequence of cuts. These *cutting instructions* refer to the figures that have been defined and also contain numerical information. The last category of statements—*special words*—provides a means for specifying necessary additional data and conveying them to the computer.

Any meaningful sequence of statements typed on a Flexowriter will yield a *program tape* that may be submitted to the computer for processing. The computer, under the control of the numerical-control processing routine, will automatically read and analyze the program tape, determine what computations are needed, execute these computations, and finally punch a control tape acceptable to the numerical director of the milling machine.

Definitions or tags

Each point, line, or circle used in a program tape must be tagged with a distinguishing symbol. When this figure is referred to, only the tag is used; the description is not repeated. The tags consist of a single lower-case letter (*p* for points, c for circles, *s* for straight lines*) followed by any integer from 0 to 255. The integers have no numerical significance; they serve only to distinguish between tags. Thus, c1 and c2 represent different circles, but c1 refers to the same circle throughout the tape.

A tag is defined by a definition statement, formed by typing the tag to be defined, then an *equals* sign, followed by a description in simple notation, of the geometrical figure associated with the tag. The definition statements recognized by the processing routine are summarized in Table I. The definitions are, for the most part, self-explanatory.

To prevent ambiguity in some of the definitions, a convention for establishing a positive direction on curves was found useful. A circle and a straight line, for instance, may intersect at two points. To say p1 = s1|c1 (the intersection of s1 and c1) is not enough. However, if the line s1 is assigned a direction, then the *near* intersection and *far* intersection can be distinguished. The statements p1 = *N*s1|c1 or p1 = *F*s1|c1 are accepted as meaningful by the processing routine, but the statement p1 = s1|c1 is not (error detection is discussed later).

The positive direction on a circle is clockwise, and

* The reason for using *s*, rather than *l*, for lines is rather interesting. Although the keys for *l* and 1 are distinct on the Flexowriter keyboard, many typists habitually strike *l* when they mean 1. To anticipate this source of error, the processing routine was written to accept either the code for *l* or the code for 1 to mean the number. A different letter is therefore needed to tag straight lines.

The letter *o* and the number 0 are also synonymous to the processing routine, both being treated as a number.

the point of minimum x is always used as the starting point in determining *near* or *far*. On a line, the choice of positive direction is left to the programmer. The positive direction will always be *from* the first point used (or implied) in the definition toward the second point. Thus, the statement $s1 = p1|p2$ defines s1 to be the line through $p1$ and $p2$, directed from $p1$ toward $p2$. The statement $s1 = p2|p1$ defines exactly the same line, but with the positive direction reversed. The point-angle form of definition is the only one that does not imply two points; in this case the line is taken to be directed outward from the given point at the specified angle.

The convention for positive direction is also used to resolve ambiguities arising when tangencies are used. Two curves whose positive directions are the same at their point of tangency are called tangent, *T*; if the positive directions are opposite, they are called anti-tangent, A. These letters in the definitions permit the computer to select the proper tangent curves from several possible choices.

Obviously, the list of definition statements can be extended to include many more ways of describing points, lines, circles, and other curves. While the ones selected appear adequate for most engineering drawings, the nature of the parts being machined will, of course, have the last word.

TABLE II

CUTTING INSTRUCTIONS

Move at 7.5 in. per min in a straight line to $p3$	7.5, $p3$
Same motion, at the same time lowering the cutter 6.214 in.	7.5, $p3$, −6.214
Move at 15 in. per min along $c2$ in its positive direction to $p2$	15, $+c2$, $p2$
Same motion, at the same time raising the cutter 0.312 in.	15, $+c2$, $p2$, 0.312
Motion in negative direction along circle	4, $-c7$, $p5$
	6, $-c3$, $p2$, +4.013

TABLE III

SPECIAL WORDS

To specify tool radius	TOOL RADIUS=0.5
To specify tool to the left of cut	LEFT
To specify tool to the right of cut	RIGHT
To produce the command which stops the tool	STOP
To specify the tolerance on a circular cut	TOLERANCE=0.0005
To signify the end of the control tape	END

Cutting instructions

The definitions only describe the geometry of the piece to be produced; they do not indicate the cutter motions needed to produce it. Sometimes the figures that are defined may in fact not be cut in their entirety, while at other times cutter paths that do not coincide at all with the contours of the work may have to be introduced during the cutting. To give the utmost flexibility, definitions and cutting instructions are made entirely separate parts of the input language.

The movements that can be described by cutting instructions are limited to those along a straight line or along a circular arc. With each, a simultaneous displacement of the cutter in the third dimension may also be specified.

The form of the cutting instructions is shown in Table II. The first figure is always the feed rate (in inches per minute). For straight-line motions, this is followed immediately by the tag of the point to which the cutter is to move. For motion along a circular arc, the tag of the appropriate circle (and a + or — sign to indicate direction) must intervene between the feed rate and the tag of the destination point. The last piece of information (omitted when not required) gives the amount of vertical rise or fall of the cutter in inches during the motion.

Only the destination point need be mentioned, because the cuts are executed in sequence by the machine tool. Initially, the cutter is assumed to be centered over the point 0,0.

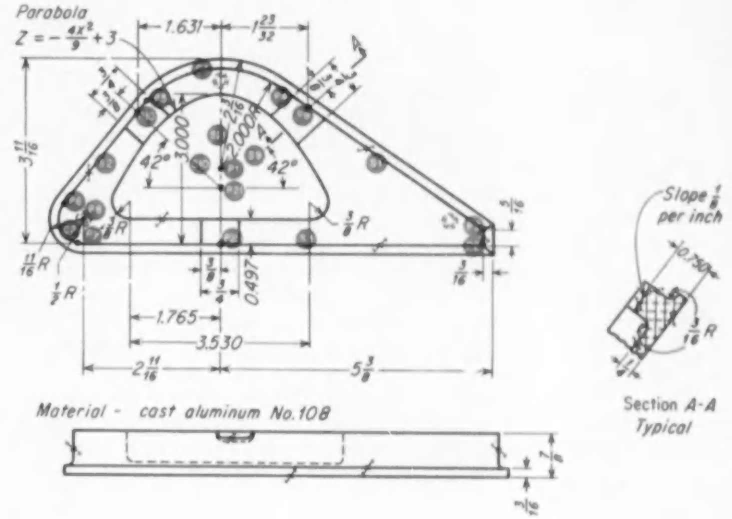
All points and curves in the cutting instructions are on the work. Actually, however, the cutter's path is displaced by one tool radius from the surface being cut. These *cutter-center offsets* are calculated automatically by the processing routine; the programmer deals only with the piece as shown on the engineering drawing, communicating cutter radius to the computer via a special word.

The special case of zero feed-rate is of interest. An instruction such as 0,p1 cannot, of course, be obeyed. However, the processing routine is designed so that this instruction, itself unworkable, causes a useful modification in the way one of the adjacent commands is computed. In effect, a zero feed-rate instruction at the beginning of a sequence of cuts causes the starting point for the following cut to be calculated as if the cutter had come from the point mentioned in the zero feed-rate instruction. Similarly, after a sequence of cuts, the zero feed-rate instruction causes the end point of the preceding instruction to be computed as if the cutter were going to the point that the zero feed-rate instruction specifies.

Special words

The special statements, shown in Table III, provide the processing routine with information that

PROGRAMMING A TYPICAL WORKPIECE



The workpiece shown in the sketch typifies projects that can be handled by the input language described in this article. The parabolic portion of the internal contour has to be subdivided into straight-line segments for programming, but the geometry of the rest of the part is suitable for the automatic-processing routine. Only the external contour and the three slots are programmed here.

The part is initially positioned so that the cutter is centered over *p*1, 4 in. above the bottom of the work.

Thus, *p*1 = 0,0

First define the external contour.
Simple arithmetic yields *p*2 = 5.1875, −1.5
*p*3 = 5.1875, −1.1875
*p*8 = −2.6875, −1
The two circular arcs are readily defined as *c*1 = *p*1|2
and *c*2 = *p*8|0.5
To obtain *p*4, first define the auxiliary line *s*1 = *p*3|*Ac*1
so that *p*4 = *Ns*1|*c*1
Similarly, the auxiliary line *s*2 = *Tc*2|*Tc*1
gives *p*5 = *Ns*2|*c*1
and *p*6 = *Ns*2|*c*2
The line *s*3 is most easily defined as *s*3 = *p*2|0°
so that, finally, *p*7 = *Ns*3|*c*2
The entire external contour has now been defined.

Next the cutting instructions.
A 3/4-in. diam cutter is used, TOOL RADIUS = 0.375
and the tool is to the RIGHT
of the work. The cutter is at *p*1 (0,0). Move it to *p*2, with cutter-center correction computed *as if* it had come from *p*7. The "zero feed-rate" instruction 0, *p*7
establishes the initial condition, and the instruction 15, *p*2
accomplishes the horizontal motion at full speed (15 in. per min).
Lower the cutter at full speed almost to the work surface, 15, *p*2, −3
and the rest of the way at 4 in. per min 4, *p*2, −0.8125
as it cuts into the work. With the tool at the required level, proceed about the contour 4, *p*3
4, *p*4
until the circular cut is reached.
State the tolerance (it could have been specified earlier), TOLERANCE = 0.005
and continue with the cutting instructions 4, −*s*1, *p*5
4, *p*6
4, −*c*2, *p*7
4, *p*2
to the end of the contour. The zero feed-rate instruction 0, *p*3
causes the cutter-center offset at *p*2 to be properly computed.
Raise the cutter clear of the work 15, *p*2, 0.8125

Now to program the three slots define the line *s*21 = *p*1|90°
to give *p*25 = *s*21|*s*3
To obtain the corresponding points for the other two slots, first define *p*20 = 1.71825, 0
so that it is possible to define a line through it *s*20 = *p*20|90°
Then define *p*9 = *s*1|*s*20
By defining *s*9 = *p*9|42°
obtain *p*21 = *s*9|*s*21
Then, the line *s*10 = *p*21|138°
yields *p*10 = *s*2|*s*10
Because of the slope of the slots, it is convenient to have the cutter move a known distance while they are being cut.
Therefore define three new points within the hollowed-out region of the piece.
Set *c*25 = *p*25|2
to give *p*252 = *Fs*21|*c*20
and similarly, *c*9 = *p*9|2
*p*92 = *Ns*9|*c*9
*c*10 = *p*10|2
*p*102 = *Ns*10|*c*10

Now cut the slots. Since cutter-center offsets must not be computed for these motions, set TOOL RADIUS = 0
and move the cutter at full speed to *p*25 15, *p*25
Lower the tool to the required height 4, *p*25, −0.250
and cut the bottom slot 4, *p*252, −0.250
Moving the cutter to *p*102, 15, *p*102
cut the left-hand slot, 4, *p*10, + 0.250
lift the tool clear, 15, *p*10, + 0.250
and move it to *p*9, 15, *p*9
Lower the tool again, 4, *p*9, − 0.250
and cut the right-hand slot 4, *p*92, − 0.250
Finish by returning the cutter to its initial elevation, 15, *p*92, 3.5
and to its initial horizontal position 15, *p*1
Terminate the program tape END

does not fit into either of the other forms. The tool radius is needed to compute machine commands, including cutter-center offsets. So is the specification of the location of the tool with respect to the surface being cut (is it to the right or left?). Each of these statements remains in effect until another statement contradicting it appears. Thus, the information need be typed only once unless a change is required during the cutting operation. This is true also of the tolerance, used by the processing routine in approximating a circular cut by a sequence of straight lines. The word STOP stops the machine tool, and the word END terminates a program tape.

The example on the preceding page shows a complete programming procedure.

Error detection

The MIT routine detects incorrect notation as well as more obscure errors that become apparent during computation. Because of the free use of implicit symbols, it is not always easy to recognize, for instance, that a nonexistent intersection has been requested, or that a motion outside the limits of machine-tool excursion has been specified. The processing routine detects as many blunders of this kind as could be anticipated. The routine maintains a count of the statements it has processed, and if an error is found, it identifies the offending statement and describes it in English.

Some errors make further processing impossible, and the routine stops. However, if the mistakes are relatively minor, the processing can continue until all are found. In this way, the programmer is presented with as complete a description as possible of what is wrong. Most errors probably result from mistyping, especially when the system is first introduced, although some significant mistakes in programming may also be uncovered by the routine.

The digital computer

The MIT processing routine occupies about 5,000 registers in Whirlwind I. This exceeds the rapid-access memory capacity, not only of Whirlwind I, but of most commercial computers. The routine is divided into sections, each being automatically brought into the magnetic-core memory as needed. The sections are stored on an auxiliary magnetic drum; magnetic tape would reduce speed.

The statements being processed and the numerical data derived from them are also stored on the drum. Since the numerical quantities may be required in a random sequence, the search time, if magnetic tape were used, would be prohibitive. The MIT routine can handle 256 each of points, lines, and circles within one problem; only a large auxiliary-storage drum permits such a large maximum number.

The computations are done by floating-point arithmetic, logical operations by fixed-point techniques. In Whirlwind I, the floating-point operations are programmed, and existing service routines are used. The logical decision-making facilities are provided by the computer's own instruction code.

The larger, more elaborate commercial computers, such as the IBM 700 series, UNIVAC, and UNIVAC Scientific, can easily provide all of these facilities. The smaller, relatively less expensive commercial computers can, too, but they operate more slowly. A magnetic drum is almost universal as the primary internal storage in the latter computers, with magnetic tape the only secondary medium. Their speed, however, is "low" only in a relative sense; in fact, the speed of any general-purpose computer is so fast compared to machining time that it is available for additional work, such as preparing the programs for other machine tools.

For a routine like the one described here, the smaller computers suffer principally because of their limited random-access memory. This necessitates the use of magnetic tape. The tapes should be used for instructions rather than numbers, since the sequence in which the instructions will be needed can be predicted, and the waiting time reduced. By judiciously segmenting the processing routine on tape, and by limiting the maximum number of points, lines, and circles, a fairly useful routine should be realizable on some of the drum computers. The storage problem will, however, be a stringent one, particularly with programmed floating-point operation, so that the length (and therefore the versatility) of the routine may have to be reduced.

[As pointed out previously, a fixed-program special-purpose computer, permanently wired to carry out the specific machine-tool programming routine, can also be used. Two of these are now available: the Electronic Control System, Inc., system, designed to handle circles much as the MIT system; and the Ferranti Ltd. system, designed to handle any conic section. Both of these systems are adapted for three-dimensional control. It is interesting that the Giddings & Lewis Numericord System[2] (patterned after the MIT numercial director) records the output of the director synchros as a phase-modulated signal on magnetic tape, rather than connecting directly to the machine-tool power servos. One director thus can service many machine tools. With this system, a special-purpose computer can be combined with the director for simplified initial programming and one central computing facility, with no data-processing at the machine tool.—Ed.]

The development of the machine-tool programming routine described here was carried out at the MIT Digital Computer Laboratory with the close cooperation of Servo Lab. personnel.

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Controlling a Nuclear-Driven Gas Turbine

- **IN A CENTRAL STATION**
- **ON BOARD SHIP**

An efficient way to use nuclear power is to drive a gas turbine directly with the gas that cools the reactor. This eliminates intermediate heat exchangers, which are required with liquid-cooled reactors, and reduces the size and complexity of the system. Since this is a new technique—no plants of this type have been designed or built—there are no precedents for many of the process and control-system design factors. However, feasibility studies have been run on two applications: a small central-station unit and a marine propulsion plant. Here, for the first time, are the tentative solutions to the control problems posed by integrating the reactor, turbo-machinery, and auxiliary equipment along the lines of the new technique.

MILTON LOWENSTEIN
Ford Instrument Co., Div. of Sperry Rand Corp.

Turbines can be driven by gases entering at high temperature and pressure and exhausting at lower temperature and pressure. The energy contained in the entering gas is converted into mechanical energy by the turbine. In conventional gas-turbine engines, the hot gases are produced by drawing in atmospheric air, compressing it, adding fuel, and burning the mixture. This is termed open-cycle, because the exhaust gases are returned to the atmosphere. In contrast, a closed-cycle is one in which the same gas is continually recirculated through the system: the gas is heated by passing it over a source of high-temperature energy. In the past, this source of energy has been a flame—it can also be a nuclear reactor.

The closed-cycle system has several advantages: the gas is clean; it can be chosen for certain desirable properties; cycle efficiency is high over a wide range of load; and, in the case of a nuclear heat source, no intermediate heat exchanger is required. This last point is important. In almost all nuclear power plants proposed or built to-date, the heat cycle has acquired at least one heat exchanger to transfer heat power from the reactor coolant to the working fluid of the power cycle (usually water). This is inefficient, increases size, and complicates control problems. The closed-cycle gas-cooled plant solves some problems—but it introduces others.

The designs discussed here have certain limitations. At present, the required turbo-machinery is available only for plants up to about 15 megawatts output. This material is based on two economic and technical feasibility studies performed by Ford Instrument Co. One is for a small central station for a municipally owned utility in Holyoke, Mass., Figure 1; the other is for a propulsion plant for an oil tanker to be built by the U.S. Maritime Commission, Figure 2. A small compact plant is particularly important in the latter case.

The control of the reactor and the power-plant cycle is a major design problem, especially since there are no precedents to follow. The controls must be designed as an integrated system so that the reactor and heat-cycle controls operate together satisfactorily. In the heat cycle, temperatures, pressure drops, and flows must be measured—valves, coolers, and output must be controlled. In the reactor, temperatures, neutron fluxes, and period must be measured—regulating and shim safety rods must be controlled.

Heat-cycle operation

Figure 3 shows the basic gas-flow cycle for a small central station unit for generating electric power (the cycle for the model shown in Figure 1). The reactor outlet gas at a high level of thermal energy enters the turbine, where part of the thermal energy is converted to mechanical shaft power. The turbine drives the required low-pressure and high-pressure compressors, and the main system alternator. After expansion in the turbine, the gas (still at high temperature) flows through the recuperator, where some of the heat is recovered, and then through the precooler, where the gas is cooled to its lowest cycle

CENTRAL-STATION UNIT

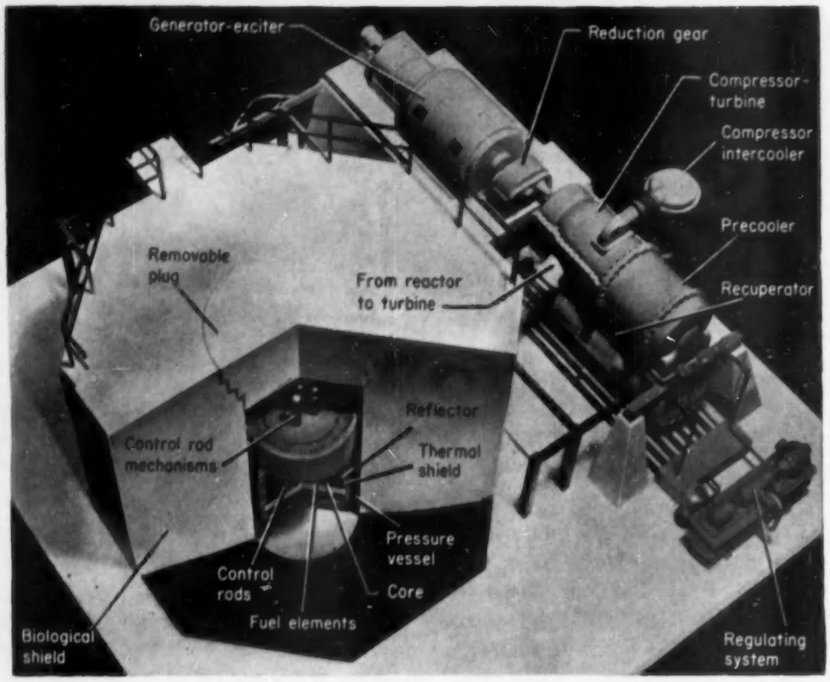

FIG. 1. Model of 2,000-kw closed-cycle gas-turbine nuclear reactor power plant: reactor design by Ford Instrument Co., rotating machinery by American Turbine Corp. in conjunction with Escher Wyss of Zurich, Switzerland. The proposed 15,000-kw nuclear power plant for the city of Holyoke, Mass., is based on design principles of existing fossil-fuel-fired equipment of the type shown here.

temperature. The low-temperature low-pressure gas is then compressed in the low-pressure compressor section, cooled in the intercooler, further compressed in the high-pressure compressor, and returned to the recuperator for preheating. From the recuperator it returns to the inlet of the reactor.

The gas-flow cycle for a marine propulsion plant is quite similar, as shown by Figure 4 (this diagram shows only basic gas flow and does not include any of the control means). Gas from the reactor flows to a high-pressure turbine which drives the main compressors and the ship's-service alternator. The starting motor for the system (energized by an auxiliary diesel-generator unit) is also on this shaft. The gas leaving the high-pressure turbine is expanded to its lowest cycle pressure in the two low-pressure turbines, which drive the screw through a set of reduction gears. The gas from the low-pressure turbines flows through a double set of recuperators, precoolers, compressors, and steam generators, back to the reactor. In the steam generators, part of the thermal energy is used to generate steam for ship's service.

Heat-cycle control

The closed-cycle gas-turbine system is controlled by a schedule different from most other power plant control schedules, but well suited to the nuclear reactor as a heat source. Control is obtained by varying the mass rate of gas flow in the system while maintaining the reactor outlet temperature constant. As shown in Figure 3, gas is bled from the system via the bleed line to reduce power output, and is added to the cycle via the inject line to increase power output. A constant high reactor outlet temperature (about 1,300 deg F) is necessary to keep the efficiency uniformly high over a wide range of loads. This is because the efficiency of the Carnot cycle is limited to a value equal to the ratio of the temperature difference in the cycle (high minus low) to the maximum absolute temperature in the cycle. This ratio can be kept high by maintaining the highest cycle temperature at a high value. For this reason, reactor power level must be closely controlled: overshoots can be damaging, and undershoots can reduce efficiency and output. Since the gas is bled from a point just before the inlet to the low-pressure compressor and injected just after the outlet of the high-pressure compressor, a transfer compressor must be used to raise the pressure of the gas in the low-pressure accumulator to that of the high-pressure accumulator. The valving at these two points is a critical element of the control system.

Several problems arise in the design and mechanization of this system. The injection and extraction of gas takes place at localized points in the cycle. The pressure close to these points reaches the new operating point more rapidly than it will elsewhere, since pressure changes in gases are not transmitted instantaneously. A nonstationary transient is set up. Methods of handling a phenomenon of this type have been published, and theoretical and experimental results agree quite closely[1]. And although experience has been limited to fuel-fired, rather than nuclear, closed-cycle gas-turbine plants, the use of a reactor would not affect the general results.

Another problem, more practical than theoretical, concerns the hardware used in the control of gas flow. Leakage of the gas coolant (nitrogen) can be serious since it becomes mildly beta-active after exposure to neutrons in the reactor. The beta rays

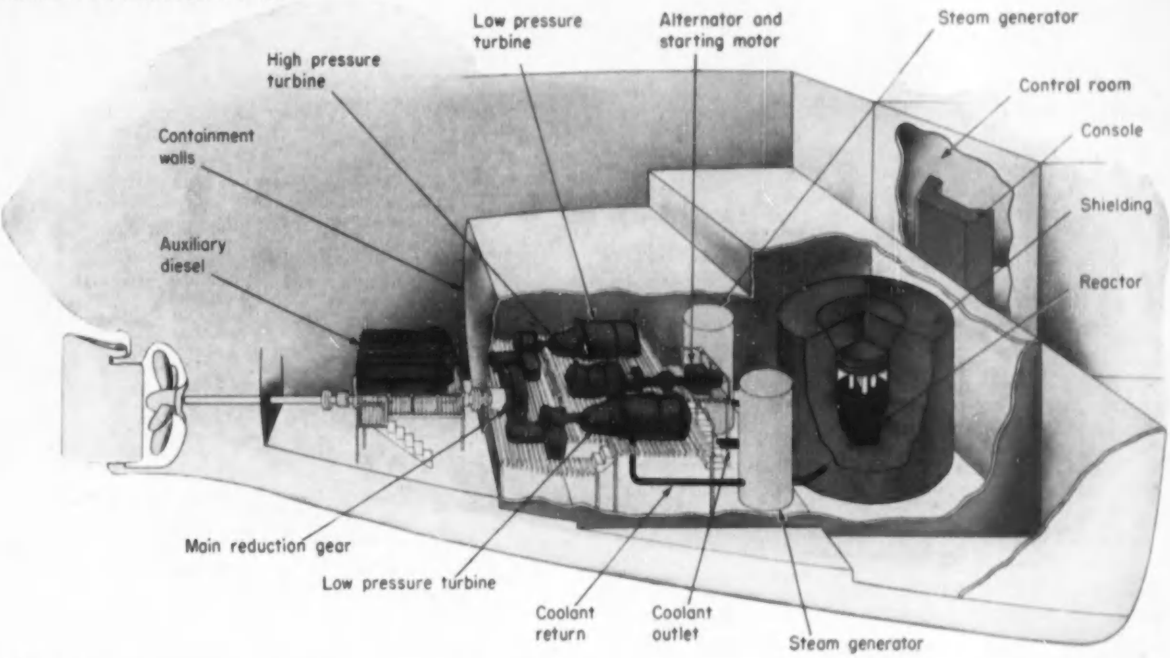

FIG. 2. Proposed layout of closed-cycle gas-turbine nuclear propulsion plant for U. S. Maritime Commission's 38,000-ton supertanker: reactor design and system coordination by Ford Instrument Co., prime contractor; machinery by Nordberg Mfg. Co.

do not penetrate the wall of the machinery, so that there is no direct danger to personnel, but gas leakage raises the possibility of inhaling this radioactivity, and this can be dangerous. Therefore, all leakage must be prevented. One precaution is to place the control valves in thimbles inside the pipes to exclude the possibility of leakage around valve stems, and actuate them by solenoids that receive their power through static seals in the pipe walls. The thimbles can be cooled externally, but even here, the electrical windings are subjected to temperatures in excess of those specified for any common insulation. A recent technique is to use oxide-coated conductors.

Another precaution is to seal the shaft inlet into the turbine-compressor against outward leakage. A positive pressure shaft seal—one which jackets the seal with clean nitrogen at pressures higher than those that exist inside the turbine-compressor—allows some leakage of clean uncontaminated gas, but none of the beta-active gas.

The method of control described above is suited to slow variations of power demand, and may be all that is required for central station power, where the plant is used for base load and where variations in demand are somewhat predictable. For a marine power plant, however, maneuvering produces variations that are unpredictable and that occur at more rapid rates. Three types of power-level change are normally encountered:

1. *Rapidly varying power demand*—occasioned by quick change of speed and direction of the vessel.

2. *Rapid change of power level*—from one steady-state condition to another, resulting from the vessel entering dangerous waters.

3. *Slow change of power level*—from one steady state to another, resulting from an approach to port.

The slow change of power level from one steady state to another (item 3) can be handled by bleeding and injecting gas as discussed above. But for the rapidly varying power demand (item 1), a means is needed for more easily controlling blocks of power. As shown in Figure 1, it can be accomplished by bypassing high-temperature high-pressure gas around the turbine to the recuperator. Quick reductions in power demand can be handled by varying the opening of the bypass valve, although this procedure causes reduced efficiency. The rapid change of power level (item 2) requires a combination of the two approaches. The rapid part of the power reduction is handled by bypassing the turbine. Then gas is bled slowly from the system through the bleed line and the reactor responds by reducing its power level. As this process continues, the bypass valve slowly closes, and the transient dies out as the new lower steady state is achieved.

Power increases can only be achieved by waiting for the cycle to respond to increased gas pressure, and the reactor to respond to increased demand. Thus, the control engineer is faced with a system that can move faster in one direction than it can in the other. It is not easy to predict the effect of this type of nonlinearity on control-system transient response and stability.

Reactor control

Most reactor control systems use neutron flux as the controlled variable [2,3], since it is the most sensitive parameter and is approximately proportional to the power level of a reactor. Thus, controlling neutron flux controls power level. However,

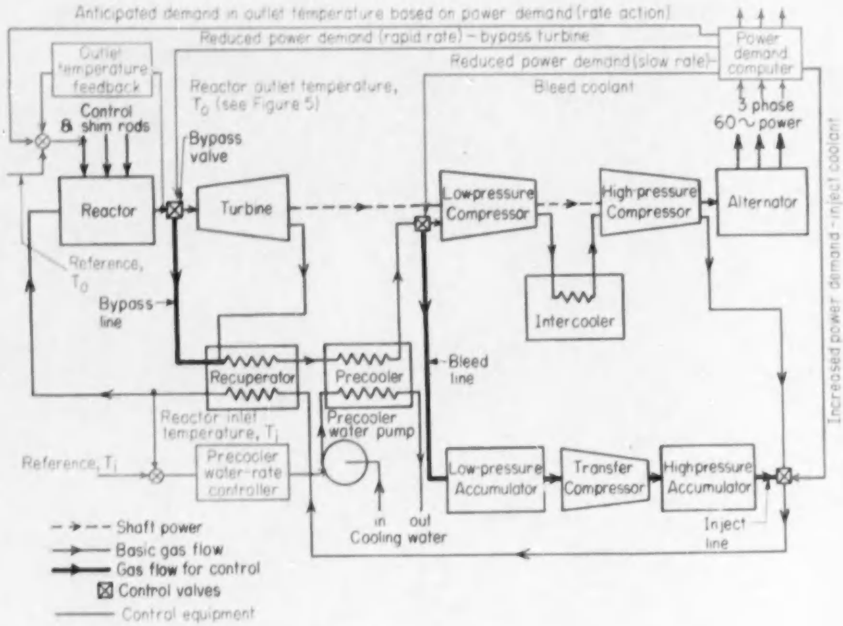

FIG. 3. Basic gas-flow and control circuitry for closed-cycle gas-cooled reactor central-station power plant, including bypass, and bleed and inject lines for power-level control under fast and slow load change. Also shown is control loop for reactor-inlet gas-coolant temperature achieved by varying output of precooler circulating pump, and reactor outlet temperature control loop, including an anticipatory signal from a power-demand computer.

as described above, the heat-cycle controls will control the power level provided the reactor can maintain constant coolant outlet temperature with changes in the mass flow rate of the gas coolant. This type of reactor system is most consistent with heat-cycle requirements if the reactor control responds to outlet temperature rather than neutron density. Then a typical response to a demand for a slow decrease of power output would be as follows:

1. Coolant is extracted from the cycle, reducing the pressure and the mass flow rate of coolant.
2. Reactor outlet temperature rises as a result of the reduced cooling effect of the coolant. The reactor control system receives a signal from the outlet gas temperature sensor.
3. Simultaneously with 2, turbine power output starts to fall as a result of the reduced mass flow.
4. The reactor control responds to the increasing temperature signal by inserting the regulating rods.
5. Reactor outlet temperature stabilizes at its designed level as the transient period ends and the new steady state is established, and the rod returns to the position at which the reactor is critical.

A demand for a slow increase in power output results in just the opposite response: coolant is added, increasing the mass flow rate; reactor outlet temperature falls and turbine output power begins to rise; reactor power level and outlet temperature rise; and a new higher-power steady state is reached as the transient dies.

An important factor in reactor control is the temperature coefficient of reactivity [2, 3, 4], the magnitude of the change in reactivity as the temperature of the reactor core varies. Depending on reactor design, this quantity can be positive, negative, or zero. As the temperature rises in a reactor with a positive coefficient, the reactivity will increase, causing a further increase in temperature. This effect can produce serious instability, making it desirable to have a negative temperature coefficient of reactivity. A reactor with a large negative coefficient can be substantially self-controlling: temperature increases cause a decrease in reactivity, and temperature dips cause an increase in reactivity. The result is a constant core temperature.

Most water-cooled and moderated reactors have substantial negative temperature coefficients. However, in a gas-cooled reactor with a solid moderator (used in this system because of the advantage of high coolant temperatures), the negative coefficient might be small so that stable operation would have to be achieved almost exclusively with the external controls. There is also a time lag associated with the temperature coefficient effect. What small negative effect there is, however, improves stability margins slightly.

Mechanizing the control system

To control this gas-cooled reactor a rod must be moved. At one position of the rod the reactor is critical, i.e., power level and neutron flux are constant. The reactor can be critical at 100 watts or 100 megawatts and the control rod will be in the same position, although this position changes slowly with time due to build-up of fission products. To raise the power level, the rod must be pulled out, making the reactor supercritical and enabling it to increase power. To lower the power level the reverse action is taken. To stabilize the power level, the control rod must be returned to its critical position.

The control-rod actuator needed to perform these motions must either be built into a sealed system and

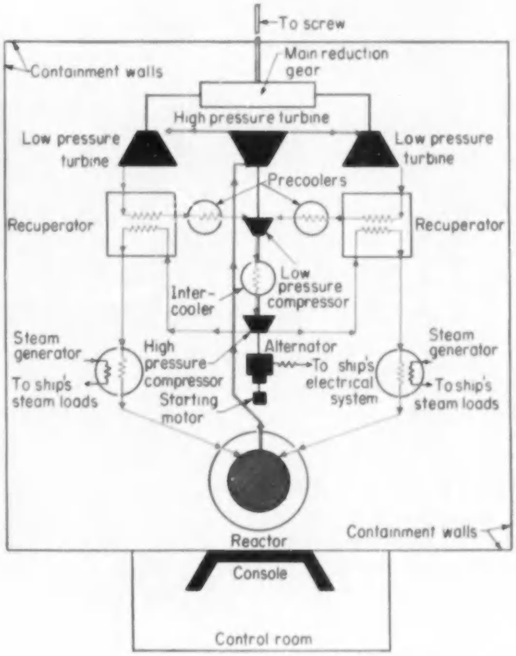

FIG. 4. Basic gas-flow diagram for marine propulsion unit. Similar to stationary unit except that gas from initial high-pressure turbine flows to two low-pressure main-drive turbines. No control circuitry is shown.

able to operate at high ambient temperatures, or be external with some means of transmitting motion into a sealed system. Both of these techniques present problems, and a final solution has not been reached. Existing reactors using water or other coolants have been built using both approaches.

The controller for the rod actuator can be either a proportional or an on-off device. The proportional controller gives slightly greater positioning accuracy at a cost of greater complexity. An on-off controller, or relay servomechanism, offers the advantages of simplicity, less sensitivity to noise, and greater acceleration during the initial part of a transient. Reactor control is an ideal application for a relay servo, since the servo's nonuniform characteristic is not a disadvantage, Figure 5. Preliminary stability and transient analyses using the describing function technique [4, 7] indicate that the system is stable. Future analyses will be based on analog and digital-computer studies.

Temperature feedback information is obtained from a thermocouple in the outlet gas stream. A proportional plus derivative feedback controller will be used. The derivative action is important since it exerts a stabilizing influence on the control loop, and, by responding with a signal proportional to the rate of temperature change, improves transient response by anticipating outlet temperature drift out of the dead zone of the on-off controller. It is expected that a dead zone of plus or minus 10 deg F about the desired 1,300 deg F will meet the thermodynamic and control system requirements. Temperature measuring and transducing equipment will need considerable development and adaptation to meet the accuracy, stability, reliability, and life requirements inherent in this application.

Reactor transfer functions

Because the reactor is an element in the control loop, Figure 2, a knowledge of its transfer function is important for a proper analysis of control-system dynamics. References 2 and 4 develop the transfer function that relates excess reactivity to neutron flux. There are two effects that modify this transfer function. One, which is common to all rod-controlled reactors, is the effect of rod position. The amount of reactivity controlled by a rod is greatest when the rod is in the center of the core, and least as it leaves the core. Thus, rod effectiveness is a function of its position and is nonlinear. As a first approximation, this is usually treated as a linearizable nonlinearity, assuming that the rod does not move far from the center of the core. The second modification of the transfer function results from using outlet temperature as the controlled variable. This means that the transfer from neutron density to reactor-core temperature must be developed, along with the transfer from core temperature to gas-outlet temperature. These require a critical study of the thermodynamics of the cooling process.

System transient response

The transient response of the reactor, reactor controls, and heat cycle is important. Time lags and dynamic errors influence the control of plant output in accommodating load variations. Overshoot, particularly of outlet temperature, is closely associated with the safety and life of the reactor itself. Transient response criteria can be weighted to reflect the importance of these various parameters. The criteria must be heavily weighted to suppress overshoots, particularly those above 1,300 deg F.

Many disturbances can change the steady-state operation of the process: changes in load demand; variations in cooling effectiveness of the precooler, intercooler, or recuperator, resulting from temperature changes in the cooling water or other effects; changes in coolant flow rate; and increase in reactor poisoning. The effect of one of these changes can be a gas-coolant outlet temperature rise, with a slope varying from gradual to abrupt. A sharp temperature rise will most likely cause a temperature overshoot, unless it is anticipated and control action is taken in advance of the normal limit of the dead zone. This is the reason for using derivative feedback in the temperature control loop. Figure 6 shows the reactor outlet temperature versus time, as gas is extracted from the cycle on a very rapid schedule. No control action is assumed. As indicated, the outlet temperature can rise rapidly. The points marked on the temperature curve show the time at which

control action would be taken for various values of the coefficient of the derivative feedback term. This coefficient is determined by using the most rapid temperature rise associated with a normal condition, and tailoring the transient response to this condition. More rapid abnormal temperature rises are a responsibility of the safety controls.

Shim control

The position of the control rod for critical reactor operation remains fixed for only short periods of time. After operation at continuously high-power levels, two effects combine to cause a steady drift of the control rod out of the core in order to maintain criticality: fuel burnup and fission product poisoning. As the amount of fuel in the reactor decreases due to burnup, part of the reactivity disappears. Rod withdrawal compensates for this. As

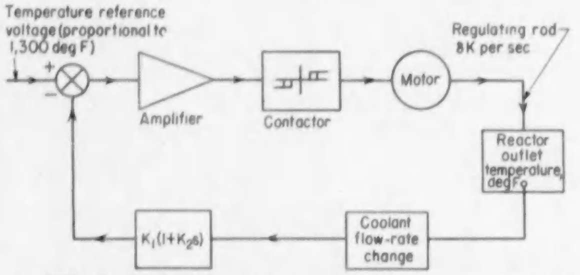

FIG. 5. Block diagram of reactor outlet temperature control unit. Regulating rod position is varied to maintain constant outlet temperature.

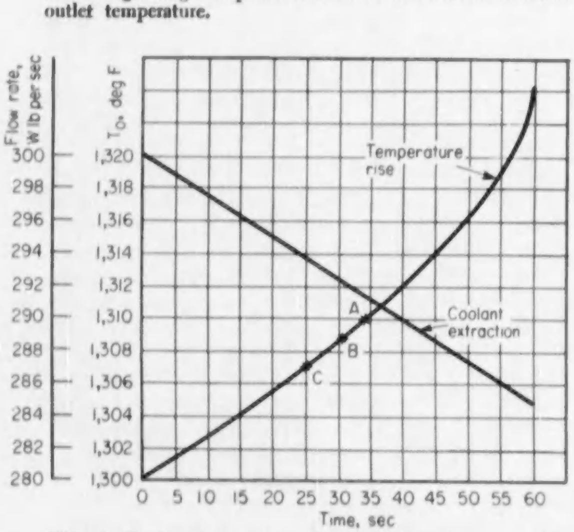

FIG. 6. Coolant extraction and temperature rise versus time. The coolant is extracted along an arbitrary straight line that reduces the flow rate by 15 lb per sec in 1 min. The calculated temperature rise is shown assuming no control action. Point A indicates end of dead zone with no derivative feedback. For cases with derivative feedback, the feedback function is K_1 (1 + K_2s). Point B indicates end of dead zone with K_2 = 4.0, and point C with K_2 = 10.0. Control response with no derivative action takes 34 sec after initiation of transient; with K_2 = 4.0, 31 sec; and with K_2 = 10.0, 25 sec.

U235 fissions, the products of the fission accumulate in the fuel elements. Some of these fission products are strong absorbers of neutrons, so that loss of neutrons to the chain reaction due to absorption also causes a loss of reactivity. Again, rod withdrawal compensates. Eventually, the control rod will reach the end of its travel, and unless its effectiveness is restored, the reactor must be refueled.

This is the purpose of the shim rods. They absorb the large amounts of excess reactivity initially built into the reactor to make the time between refuelings as long as possible. Withdrawing the shim rods a small amount restores the effectiveness of the control rod. This can be done automatically by placing a limit switch near the top of the control-rod travel. When the control rod reaches this point the limit switch would close, causing the shims to withdraw a fixed amount, whereupon the control rod would return to the bottom of its travel to begin its upward drift once again. When the shim rods reach their upper limits, the reactor must be refueled.

Safety control

In a certain sense, safety controls are more important than the regulating system, since they must take over when everything else fails. The instrumentation shown in Figure 7, besides actuating the safeties, indicates to the operator the source of failure. This facilitates correction or repair. There are safety channels associated with nuclear properties, such as period and neutron density, but these are common to all types of reactors. In a gas-cooled reactor, reduced or stopped coolant flow is a particularly important mechanical failure that can result in severe damage to the reactor unless the chain reaction is halted and standby cooling provided. Devices sensitive to cycle pressure, coolant mass flow rate, coolant temperature, and reactor pressure drop constitute the safety instruments for coolant conditions. Excess fuel-element temperature is also a sensitive measure of trouble. The action following a signal in any of these safety channels is either a setback, if the situation is slightly abnormal, or a "scram", if safe limits are greatly exceeded. A setback will drive all rods, shim and control, into the reactor at their maximum normal speeds. A scram will drop and propel the shim rods into the core with a force equal to gravity plus the stored energy in a spring or some other device. The scram condition is a last resort, and should not be used when the safety of the reactor or operating personnel is at stake. Hence the provision for a setback.

One other dangerous condition can exist in a reactor system where the primary coolant flows through the turbo-machinery. The coolant stream can become radioactive due to the rupture of a fuel element. A water-cooled reactor, for instance, which uses a heat exchanger to connect the primary loop to the secondary loop, usually has a shielded heat exchanger. The primary water coolant becomes

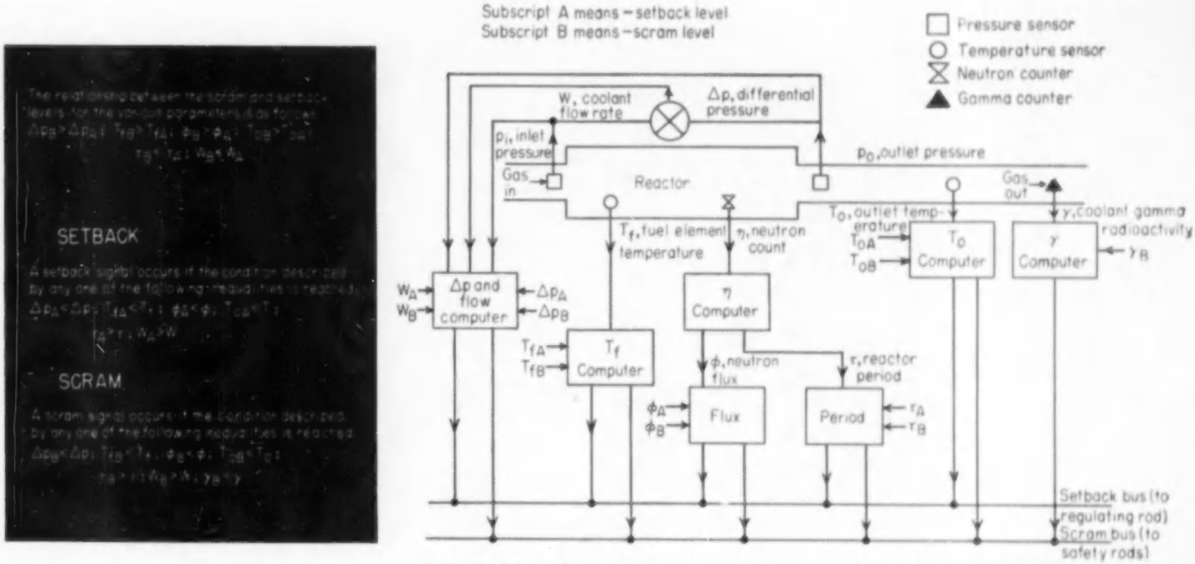

FIG. 7. Block diagram of reactor safety system. Computers calculate the necessary parameters and compare the actual value of each of the critical parameters with the setback and scram levels. If any one of the inequalities is exceeded, a signal is generated (either setback or scram) to reduce reactivity.

radioactive because it passes through a high neutron flux, but it cannot transmit its radioactivity to the secondary coolant because neutrons are not present in the heat exchanger. This allows men to work safely near the turbo-machinery. The coolant for the gas-cooled cycle is chosen for low induced radioactivity. If it is nitrogen, some will be converted to radioactive carbon-14, which is a beta emitter. Since beta rays have low penetrating power, the walls of the turbo-machinery offer sufficient protection. But fission products that are gamma-active will penetrate the walls and are dangerous. If the gamma activity of the coolant is high, a scram should be initiated, because a fuel element has ruptured.

Careful attention must be given to the design of the shim-safety rod actuators. When a scram is initiated, the rods must accelerate rapidly. Dropping at a high velocity, they can be destructive when they reach the bottom of the core unless their motion is damped or snubbed. The main problems of safety-rod design are to attain quick release after a scram signal, high initial acceleration, and effective deceleration at the bottom of the stroke.

Other problems

Reliability is one of the major design problems of reactor control systems. Overdesign is preferable to underdesign and is necessary in the absence of accurate design criteria. Care must be taken to protect personnel from a possible nuclear incident. Repairs are difficult and time consuming, since mechanisms in the vicinity of the core can be reached only after complete reactor shutdown and removal of the fuel elements. Since a major advantage of a reactor power plant is the long time interval between refuelings, removal of the fuel elements should not take place more than once a year. At this time, all instrumentation and control components inside or close to the pressure vessel can be removed and replaced if necessary. If simple and rugged, these components should require no attention at other times. As in most practical applications of nuclear power, material characteristics are the most significant limitation.

Startup and shutdown also require consideration; however, since they occur at rather infrequent intervals, automatic control may be desirable but is usually not strictly necessary[4]. Health monitoring for personnel safety is important, and is accomplished by placing area survey meters in and around the plant, and by equipping personnel with pocket dosimeters and film badges.

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Applying Power Transistors to Control

Power transistors merit considerable interest as a control component, not only in view of their present usefulness but also because of their promise of even higher power ratings and extreme reliability in the future. In this article the author concentrates on the application of transistors and skips over the intricacies of their internal operation. He does, however, review those transistor and circuit characteristics for electrical and thermal design.

Recognizing that temperature and heat-dissipation problems limit the usefulness of power transistors, Mr. Aronson introduces the concept of the thermal analog. Numerous charts and design equations used in conjunction with this concept assure a thermal design that allows maximum utilization of the transistor's power capabilities without self-destruction because of thermal instability.

The inclusion of the design of a typical servo amplifier, one of the major applications of transistors in control, emphasizes the fact that transistors amplify power, not merely voltage or current.

H. L. ARONSON, Baird Associates, Inc.

Power transistors are playing an increasingly important role in circuits designed primarily for control applications. The advantage of transistors in low-power applications are already well established, the most notable of these applications being the alliance of transistors with magnetic amplifiers for preamplifiers in control devices.

Prior to the early part of 1954, most applications of power transistors were neither economically feasible nor adequately reliable. Even today, with improvements and lower cost opening the way for more wide-spread use of transistors in control, the decision to use a power transistor in place of its vacuum tube counterpart is not a simple one to make.

Before discussing technical aspects, such as transistor parameters, circuit design factors, and thermal considerations, it might be worthwhile to review transistor advantages and disadvantages. Table I shows some major ones.

Table II presents the three basic configurations found in transistor circuitry (common base, common emitter, and common collector), and indicates the degree of their usefulness in specific applications by a list of their more important characteristics and range of parameters.

POWER TRANSISTOR PARAMETERS

A number of parameters describe the behavior of a transistor. Some of these may be given in terms of either small-signal or large-signal characteristics. In general, the small-signal parameters are more basic (but accurate only for power circuits operating within the transistor's linear region), while the large-signal parameters are more meaningful for large current excursions (but vary with configuration and circuit in a manner that is difficult to correlate). Therefore, the design of any circuit subject to large signals usually requires calculation or measurement.

Peak or average measurements may also be used when describing a transistor's parameters. For most purposes peak large-signal measurements are more desirable, because they define the situation at maximum dissipation and also guarantee that maximum power can be obtained from a design. The recommended measurement with individual parameters will be discussed below in conjunction with a description of these parameters.

► Input Impedance—A transistor's input impedance

varies with operating point. This variation affects the amount of power drawn from the driver stage (since the input impedance serves as the driver stage's load impedance), and therefore affects the amount of power delivered at the output (since the transistor acts as a power amplifier). It thus becomes necessary to determine the input impedance and its variations for each application. If the peak collector current ($\cong E_c/R_{load}$) for the desired output power is known the required input voltage and current can be obtained from the transistor's characteristic curves. Their ratio is, of course, the input impedance at peak output power.

► Current Gain—This is the ratio of peak collector current to the input current which generates the collector current. It is also a function of the operating point and may be determined in somewhat the same way as the input impedance is obtained.

► Output Impedance—In most power transistor applications the output impedance is not important, since it is many times larger than the load impedance. An exception is when driving a servo motor, which requires a low impedance source; then the amplifier gain will be independent of motor impedance changes such as occur between running and stall conditions. If the circuit is already constructed, the output impedance can be found by varying the load impedance and measuring the voltage change. Otherwise, it can be found by analyzing the transistor's characteristic curves: measurement of the slope of the common emitter characteristics at the desired operating point yields the common emitter configu-

Table I TRANSISTOR ATTRIBUTES

ADVANTAGES

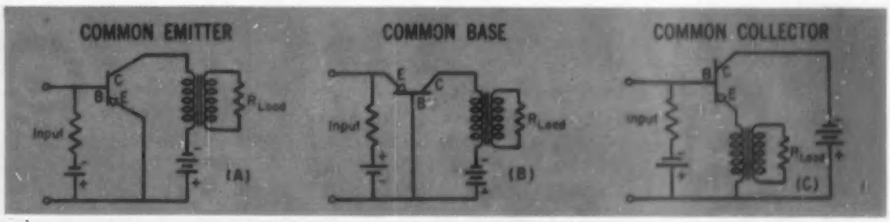
1. Reliability—The power transistor is inherently an extremely reliable device. Presently available figures indicate life expectancies at least twice as good as the best available vacuum tubes. But more important: there is every reason to expect the operating life of future power transistors to be considerably better.
2. Ruggedness—Transistors are many times less sensitive to vibration and shock than vacuum tubes. Thus, they may be used without requiring shock mounts.
3. Simplicity—Transistorization frequently lends itself to mechanical and electrical simplification because of simpler wiring and reduced heat dissipation.
4. Reduced Size and Weight—Not only are transistors themselves smaller than comparable vacuum tubes, but associated components may also be smaller because of the lower voltages used in transistor circuits.
5. Reduced Power Supply Requirements—This advantage accrues primarily from elimination of filament power. However, plate efficiencies of transistors are comparable to vacuum tubes. Another power saving results from the transistor's ability to operate close to the theoretical efficiency in many circuits.

DISADVANTAGES

1. Temperature limitation—Transistor temperature, not power, is the fundamental limit. The power rating of a transistor decreases faster with increasing temperature than a comparable vacuum tube. The heat-dissipation problem limits obtainable power output (at any ambient temperature) unless adequate heat sink and cooling techniques are used. In addition, transistors may require complex temperature stabilizing circuitry.
2. Limited Available Power Range—Production power transistors are available with nominal ratings up to 60 watts internal dissipation. Experimental models are available with ratings up to 100 watts, permitting more than 300 watts in the load. Since these ratings depend on the transistor case being at room temperature the actual power dissipated is a measure of how well the junction is cooled by cooling the case.
3. Nonlinearity—Present transistors are not as linear as vacuum tubes. However, new transistor types and manufacturing techniques have resulted in considerably improved linearity.

TABLE II COMPARISON OF TRANSISTOR CIRCUIT CONFIGURATIONS

BASIC CIRCUIT
Transistor and battery polarities shown for PNP transistor.
B—base
E—emitter
C—collector



	Common emitter	Common base	Common collector
Equiv. vacuum tube circuit	Standard grounded cathode	Grounded grid	Grounded plate
Power gain, db	28	15	10
Distortion, % harmonic	20	5	5
Input impedance, ohms	50	5	highest, depends on load imp.
Output impedance, ohms	1,000	10,000	lowest, depends on source imp.
High frequency response, kc	4 to 20	80 to 2,000	6 to 30
Comments	Most frequently used configuration, due to its high gain. But reduction of output impedance and distortion by negative feedback diminish gain.	Primarily selected because of high frequency response and excellent linearity.	With low impedance loads (as from low voltage power source) this configuration may have highest power gain. Possesses most constant characteristics over wide temperature range.

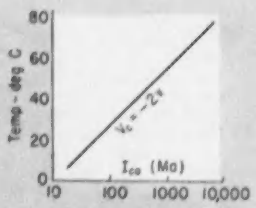


Fig. 1. Normal exponential variation of I_{co} with temperature.

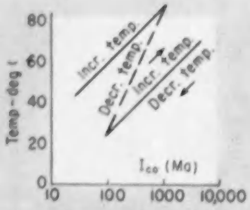


Fig. 2. Shift in I_{co} after temperature cycling.

ration output impedance. The common base configuration slope is too steep for this technique, so for this configuration the output impedance may be approximated by multiplying the common emitter output impedance by the common emitter current gain. The output impedance for the common collector configuration is approximately equal to the driving source impedance divided by the common emitter current gain.

► Internal Thermal Resistance-θ_i—A transistor's internal thermal resistance is a measure of junction-temperature rise as a function of internally-dissipated power. That is, a thermal resistance of 5 deg C/watt means that the temperature difference between the transistor junction and case increases 5 deg C for each watt of power dissipated within the transistor. Each transistor type has a very definite maximum allowable junction temperature. Therefore, its internal thermal resistance determines the maximum power that can be handled. However, other factors might limit the transistor's useful power output before this value is reached.

► Transistor Saturation Current-I_{co}—This is the back-biased collector to base current. Its temperature-sensitive behavior must be considered in the design of power-transistor circuitry because it has a strong influence at high temperatures and power dissipations. This parameter's variations with temperature is an excellent gage of the transistor's inherent reliability (Figure 1 shows normal variation), since contamination and other manufacturing weaknesses frequently show up when the measurement is made. Random variations of I_{co}, instabilities, changes of slope, and new values after temperature cycling are examples. Figure 2 shows the effect of temperature cycling, probably caused by volatile elements within the transistor. This situation is now being corrected by using welded cases and eliminating solder flux.

► Collector Saturation Resistance—A minimum collector voltage must be exceeded before the transistor will operate properly in the common emitter and collector configurations. The linear relationship between collector voltage and collector current can be represented by a collector saturation resistance. This allows the concept that the transistor operates down to zero volts but with a series resistance (of magnitude equal to the collector saturation resistance) in the collector circuit.

Typical values of this parameter range from less than 0.05 ohm for high-power germanium transistors to 100 or 200 ohms for medium-power silicon transistors. This value must be known to calculate how much of the collector voltage is available for developing output power. Also, the efficiency of a power stage can be computed if the collector saturation resistance is known. Thus, class B efficiency closely approximates: $0.78\ (1-I_{max} \times R_{sat}/E_c)$.

THERMAL CONSIDERATIONS

Many transistor-circuit design problems have their counterparts in vacuum-tube circuitry. In general, the electrical design procedure for high-power stages using transistors or vacuum tubes are more nearly identical than in low-power stages. But, except under special circumstances, the vacuum-tube circuit designer does not have to place appreciable consideration on thermal design. In power-transistor circuitry, however, the thermal and electrical designs are equally important. In the writer's experience, condemnations and failures of power transistor circuits have been caused more by a lack of understanding of the thermal factors than by inherent limitations of transistors.

Allowable power dissipation

The maximum permissible junction temperature, which determines the allowable power dissipation in a transistor, depends, in turn, on the transistor's internal thermal resistance (θ_i) in conjunction with the external thermal resistance (θ_e) of the heat dissipating arrangement (heat sink). The external thermal resistance represents the combined heat-dissipative effects of thermal conduction, radiation, and convection. Briefly, conduction is the transfer of heat from one portion of a body to another via that body. In convection a liquid or gas absorbs heat by conduction at one place and moves as a current to another place, where it mixes with a cooler portion of the fluid and gives up its heat. Radiation is the energy emitted as heat by a solid or liquid body due to the difference in temperature between the body and its surroundings, and functions in accordance with the fourth-power law.

Thermal resistance and its electrical analog

Analogies exist between voltage drop and tem-

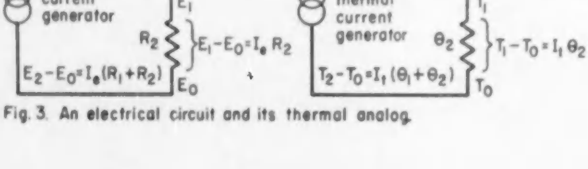


Fig. 3. An electrical circuit and its thermal analog.

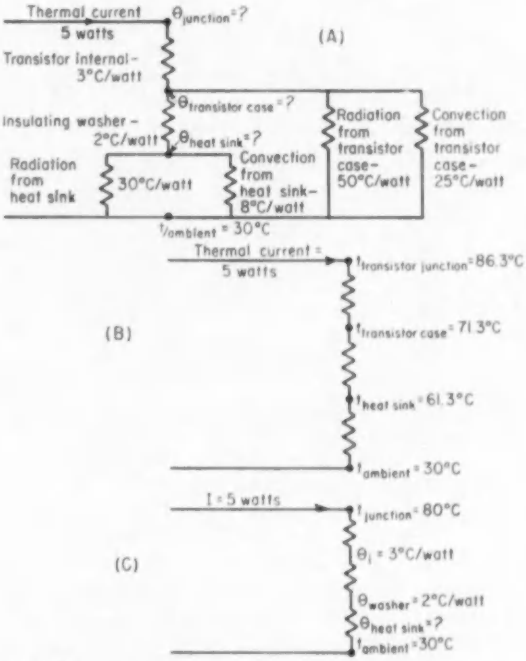


Fig. 4. A transistor thermal circuit of maximum complexity (A), its equivalent circuit (B), and a circuit to find a heat sink's thermal resistance (C).

perature drop, electrical current and thermal current, and ohmic resistance and thermal resistance. Using these analogies, thermal circuits can be visualized and calculated as though they are series and parallel electrical resistance combinations. Figure 3 shows the analogy between a simple electrical circuit and its corresponding thermal circuit.

In electrical circuits:

$$\text{voltage drop} = \text{electrical current} \times \left[\frac{\text{length}}{\text{area}} \times \frac{1}{k'}\right]$$

where k′ is the electrical conductivity and the bracketed expression is the electrical resistance.

The equivalent thermal relationship is:

$$\text{temperature drop} = \text{thermal current} \times \left[\frac{\text{length}}{\text{area}} \times \frac{1}{k}\right]$$

where k is the thermal conductivity and the bracketed expression is the thermal resistance.

The units of thermal resistance are deg C/watt of collector dissipation. This is equivalent to expressing electrical resistance as volts per ampere. Similarly, thermal current can be expressed in watts units, where (under conditions of thermal equilibrium) each watt of electrical power dissipated as heat in the transistor causes one watt of thermal current to flow.

Figure 4A exemplifies a problem of about maximum complexity found in transistor thermal circuit design. Here, the values given are typical and indicate that, practically speaking, a number of heat paths can be ignored, such as the relatively high transistor case resistance due to radiation and convection that are in parallel with smaller resistance values.

The first step in solving this problem is to reorganize the circuit to its equivalent arrangement, as shown in Figure 4B, and find the equivalent resistance for the parallel radiation and convection resistances of the heat sink: $(8 \times 30)/(8 + 30) = 6.3$ deg C/watt. The temperature drop across this resistance equals 5 watts times 6.3 deg C/watt, or 31.5 deg C. Therefore, the heat sink temperature is the ambient plus this value, or 30 plus 31.5, which equals 61.5 deg C. In a like manner the temperature drops across the insulating washer and the internal resistance are computed. This results in the complete temperature distribution from the transistor junction to ambient, as shown in Figure 4B.

A more realistic problem is shown in Figure 4C. Here, the internal thermal resistance of the transistor and the thermal resistance of the insulating washer are known, as well as the desired junction temperature of 80 deg C at 5 watts dissipation with 30 deg C ambient. The problem is to find the heat sink's thermal resistance to meet these specifications:

The allowable temperature drop from junction to ambient is 80 — 30 equals 50 deg C. Thus, the total thermal resistance, with 5 watts thermal current, equals 50/5, or 10 deg C/watt. The heat sink resistance equals this total resistance minus the thermal resistances of the transistor and washer, or $10 - 3 - 2 = 5$ deg C/watt. Knowing this, the temperature of the heat sink can be calculated: $5 \times 5 + 30 = 55$ deg C.

Determining thermal resistances

The above exercises show the benefits of the thermal analogy to electrical circuits and also the simple calculations involved if the thermal resistances are known. Actually, however, the thermal resistances must be measured or calculated from the design itself.

Since a transistor is sealed, its internal thermal resistance cannot be determined by direct measurement of the junction temperature. However, θ_i can be measured indirectly by dissipating power in a transistor for a half-cycle and then measuring the thermally-sensitive saturation current I_{co} on the alternate half-cycle. From these measurements a curve of *PD* (power dissipated) vs. I_{co} is plotted. This information is correlated against a plot of junction temperature vs. I_{co}, as obtained previously by heating the transistor in an oil bath and measuring I_{co}. These curves yield a new curve of junction temperature rise as a function of dissipated power, from which the internal thermal resistance can be found, in deg C/watt.

The results obtained by direct measurements of heat sink thermal resistance include the effects of conduction, radiation, and convection, as well as various edge, shape, and position effects. Accurate results obtain if measurements are made at the highest ambient temperature involved and with the intended power dissipation. In this direct method a resistor, which dissipates the same amount of power

Fig.A - Convection thermal resistance

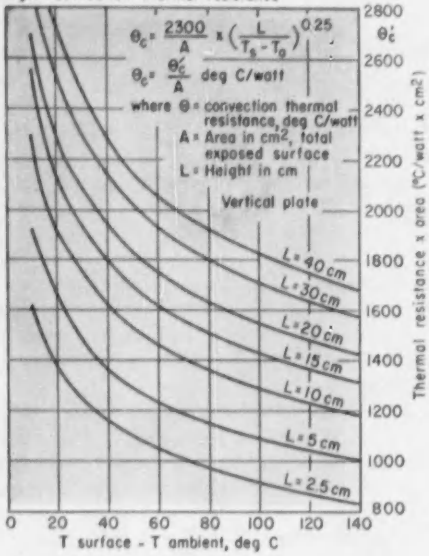


Fig. B - Radiation thermal resistance

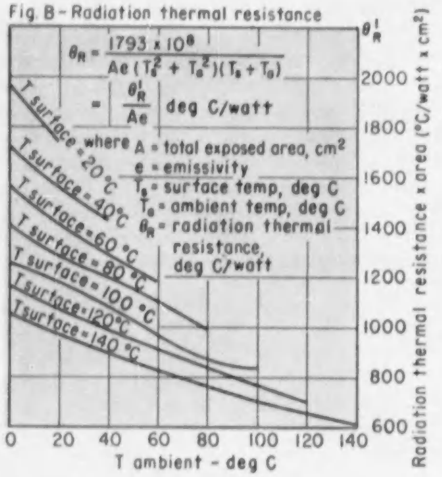


Fig. C $\frac{\text{Radiation thermal resistance}}{\text{Convection thermal resistance}}$ vs. Surface temperature

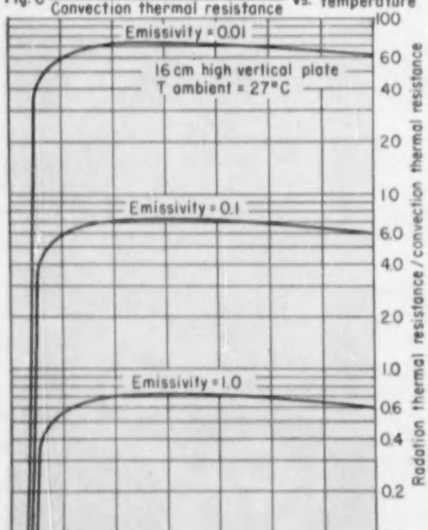


Table III THERMAL RESISTANCE DESIGN CHARTS

CONVECTION THERMAL RESISTANCE

The thermal resistance for convection is based on the formula shown in Figure A which applies to vertical plates freely suspended in air at ground level. To aid design the equation is plotted for various lengths of vertical height per unit area. The value θ'_c must then be divided by the total area (both sides of plate) exposed to air. Conversely, the total area needed for a given thermal resistance can be found from these plots.

This formula can be used for any symmetrical heat sink: for the surface of horizontal plate facing **upwards** in air—

$\theta = 0.78 \times \theta$ for vertical plates

for the surface of horizontal plate facing **downwards** in air—

$\theta = 1.56 \times \theta$ for vertical plates

where, for horizontal plates, replace **L** in vertical plate formula with ½ (length plus width). Resistances computed in accordance with the above relationship appear in parallel with each other.

CONDUCTION THERMAL RESISTANCE

When the thermal current flows through an insulator, there will be a significant temperature drop. The series thermal resistance attributable to conduction can be found from the formula

$$\theta = \frac{t}{4.19\,k\,A} \text{ deg C/watt}$$

where **k** is the thermal conductivity, cal-cm/sec-cm²-deg C

t is the length in cm of the thermal current path, usually the thickness of the insulator.

A is the area of the thermal current path

Usually, a well-designed heat sink has negligible thermal drop between its surfaces through which the thermal current flows. But when the heat sink is excessively thin or made of a poor conductor, thermal drop must be computed and considered as a series thermal resistance between the transistor and ambient temperatures. Here, the thermal resistance results primarily from conduction through the edges of the material and not between the surfaces. On this basis the above conduction equation can be modified for the following designs:

- circular plate: $\theta = 1/(\pi \times 4.19 \times t \times k)$
- square plate: $\theta = 1/(8.38 \times t \times k)$
- rectangular plate: $\theta = L/W \times 1/(33.5 \times t \times k)$, satisfactory when $L > 4W$, otherwise use square plate formula.

RADIATION THERMAL RESISTANCE

The formula for thermal resistance due to radiation is shown in Figure B, again with curves for various surface temperatures and for a unit radiating area. Area includes total exposed surface (both sides). The actual thermal resistance is found by dividing the value from graph by total area and emissivity.

CONVECTION AND RADIATION THERMAL RESISTANCES COMPARED

Usually the radiation thermal current will be less than 25 percent of the total current, depending on the temperatures, emissivity, size, and position of the surface involved. Figure C shows the ratio of radiation thermal resistance to convection thermal resistance. The higher this ratio the lower the heat dissipated by radiation. Thus, for an unpainted surface (emissivity 0.03 to 0.1) the ratio is six or seven, so radiation represents less than 15 percent of the total thermal current. However, a thin layer of paint could increase the surface emissivity to as much as 0.95, making the radiation thermal resistance about equal to the convection thermal resistance.

as the transistor, replaces the transistor, and the heat sink and ambient temperature are measured. Here, the heat sink thermal resistance equals the heat sink and ambient temperature difference divided by the power dissipated in the resistor.

When the circuit is still in the paper and pencil design stage the external thermal resistances cannot be measured directly, but they can be calculated from equations relating convection, conduction, and radiation to thermal resistance. The design procedure is simplified by converting the equations to graphs, as shown in Table III. Here, the first two graphs show the thermal resistance (for a unit heat-transfer area) for convection and radiation. Values obtained from these graphs must be divided by the actual design area to arrive at the true thermal resistance.

Thermal resistance due to conduction depends on an easily solved equation, so in Table III it is left in literal form. The third graph in the table plots the ratio of radiation thermal resistance to convection thermal resistance (for a typical application), and thus indicates under what conditions radiation resistance becomes large enough (in comparison with convection resistance) to be neglected in thermal design calculations. The part of the text associated with the table discusses other applications of the graphs and equations.

Stability factor

The stability factor S indicates the rate of change of collector current with temperature, although it is actually defined as the rate of change of collector current with I_{co}: $S = dI_c/dI_{co}$. Here, I_{co} varies in a known manner with temperature. The stability factor must be known to predict circuit behavior with changes in temperature and also to prevent thermal runaway, to be discussed in detail. Ideally, S equals unity, but actually it is some value larger than this. However, small values of S mean more stable circuits. Two independent mechanisms contribute to the temperature sensitivity of the collector current: changes in dc input impedance and the exponential increase of I_{co} with increase in temperature.

Figure 5 shows the temperature variation of input impedance of a typical germanium transistor. If this transistor is biased from a voltage source, as in class B circuits, the input current equals the bias voltage divided by the input impedance. Changes in this impedance therefore cause changes in biasing current, and hence changes the collector current. By using temperature-sensitive resistors as shown in Figure 6A, this effect can be minimized. Here, R_1 is sufficiently small compared with the input impedance so that it acts like a voltage source. The temperature-sensitive resistance, *TSR*, with a negative temperature coefficient, decreases the parallel resistance as temperature increases. Thus, the resistance combination corrects for the decreasing input impedance, because the bias voltage, too, decreases with increasing temperature and maintains the biasing current constant.

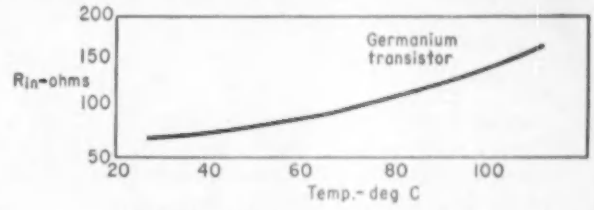


Fig. 5. Input impedance variation with temperature.

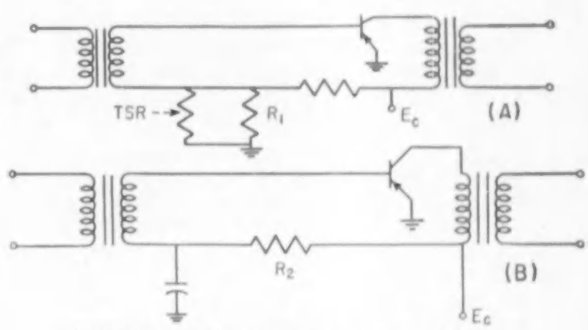


Fig. 6. Biasing from a voltage source (A), and from a constant current source (B)

Figure 6B shows a different approach to maintaining circuit stability, that of constant current biasing. Here, a large resistance is placed in series with the transistor's input impedance so that impedance variations with temperature do not significantly change the bias current.

The arrangements shown in Figures 6A and 6B are quite suitable for moderate temperatures. But at higher ones it is necessary to consider an additional factor, that of the exponential variation of I_{co} with temperature. Thus, at high temperatures I_{co} becomes larger and, in the worst case (I_b equals zero) is multiplied by the transistor gain. This multiplied current appears in the collector circuit and forms an appreciable, but undesirable, portion of the total collector current.

For low-power circuits it is quite practical to have sufficiently large resistance in the base and emitter circuits to make the impedances of the transistor unimportant. And for some high-power circuits, especially where the power-supply drain is unimportant, the same arrangement may be used. For these conditions the stability factor becomes:

$$S = 1 + \frac{\text{resistance in base circuit}}{\text{resistance in emitter circuit}}$$

Techniques for determining the stability factor for circuit relationships other than the above can be found in the RCA book: *Transistors I*. However, the following presents some of the limiting conditions:

► The poorest stability factor occurs when both the base and emitter resistances are small. In the medium-temperature range the collector current varies because of the temperature sensitivity of the transistor input impedance. (However, this will not cause

difficulty with unbiased class B operation). As the temperature is raised the I_{co} increase predominates and the stability factor approaches the worst condition, the point where it equals the magnitude of the dc current gain.

► If the base resistance is large and the emitter resistance is small, improved stability obtains over the region where I_{co} itself is small, since the bias is then independent of the transistor input impedance. As the temperature increases and I_{co} becomes appreciable the stability factor behaves as above and approaches the value of the dc current gain, but at a somewhat slower rate.

► The situation for large emitter resistance and small base resistance is much the same as given previously for the large base and emitter resistance, but now the base resistance includes the transistor's internal base lead resistance. Base lead resistance for typical transistors ranges from 100 ohms to less than 10 ohms, and with appreciable external resistance present in the base circuit the stability factor becomes higher than for the case just discussed. Thus, as the external base resistance becomes large the stability factor approaches the $1 + R_b/R_e$ relationship.

Thermal runaway

Thermal runaway results from the thermal sensitivity of the collector saturation current I_{co} and occurs when the collector dissipation due to $E_c \times I_{co}$ increases more rapidly than the flow of thermal current out of the transistor. A self-perpetuating condition then exists whereby the heat increases due to the increase of I_{co} cause I_{co} to increase further, raising the temperature further and further increasing I_{co}. If the condition continues it will destroy the transistor. The rate at which thermal runaway takes place depends on the transistor's thermal time constant, so that with a large time constant it takes longer for destruction to occur.

An equation suitable for designing a thermally-stable circuit is:

$$E_c \times S \times k \times \theta \times I_{co}(T_1) \times e^z < 1$$

Where:

$z = k(PD \times \theta + 1/k + T_a - T_1)$
PD = collector power dissipation
E_c = collector voltage
e = Naperian base
S = stability factor
k = slope of I_{co} vs. temperature—1/15 for germanium and 1/10 for silicon
θ = total thermal resistance
T_1 = temperature at which I_{co} is measured
T_a = maximum ambient temperature

This shows that to assure a thermally-stable circuit the stability factor should be as small as possible.

DESIGN CONSIDERATIONS

The design of a power-transistor stage influences the choice of transistors and circuitry. The following paragraphs briefly cover several important factors:

Maximum output power

Maximum output power influences the choice of transistor type circuit arrangements (single-ended or push-pull) and the heat-dissipation arrangements. The basic impedance-voltage relationships for transistors are the same as for vacuum tubes. But transistors attain higher efficiencies because of better utilization of available power supply voltage: the transistor operates satisfactorily as long as the supply voltage exceeds the product of the collector current and transistor saturation resistance, usually less than one or two volts.

While the basic transistor-circuit design is identical with designs using vacuum tubes, there are nevertheless some important design differences that must be considered when using transistors. For example, even for a short time the maximum ratings of the transistor should not be exceeded, unless special precautions are taken, (although this might be permissible in vacuum tubes). Furthermore, for some applications other considerations (such as linearity) reduce the useful maximum output to below the calculated value.

Class B stages also present a special dissipation problem that must occasionally be taken into account: a ten-watt push-pull class B stage dissipates an average of about 1.35 watts per transistor, but each transistor reaches a peak dissipation of about 2.5 watts twice each cycle. However, the possibility of damaging a transistor by exceeding its peak dissipation depends on the transistor's thermal time constant. Thus, for low- and medium-power transistors with large time constants the frequency of peak dissipation should be greater than a few cps, while for higher-power transistors, with smaller time constants, this minimum frequency may be 10 cps or higher. Mounting the transistor on a heat sink that remains ideally infinite for some time increases this frequency, but calculations to find it are prohibitive.

Power gain

Power gain influences the choice of transistor-circuit configuration, and in some cases the choice of power supply voltage. The power-gain relationships of power stages are essentially the same as for low-power stages. But since power stages usually operate with load impedances that are small compared with output impedances, it is possible to make some simplifications in computing power gain:

- Common collector power gain = Beta
- Common base gain = $\text{Alpha}^2 \times R_{load}/R_{in}$
- Common emitter gain = $\text{Beta}^2 \times R_{load}/_{in}$

where: Alpha is the common base current gain, and
Beta is, the common emitter current gain

From a power-gain standpoint the common emitter stage is best, followed by the common base and common collector configurations. However, the common collector stage power gain is independent of the collector voltage, making this the highest gain configuration for operations at very low collector voltage.

Linearity

Linearity is a not-too-important consideration in applying transistors to control devices, particularly when used in power stages to drive servo motors. However, it might be advantageous to show the causes of nonlinearity and some ways to improve it. The causes of nonlinearity are:

- variations of current gain with operating point
- variations of input impedance with operating point
- variations of output impedance with operating point

Typical common base current gains (Alpha) vary with respect to I_c from 0.8 to 0.98, and equivalent common emitter current gains (Beta) vary from 4.0 to 49, as found from the relationship: Beta = Alpha/(1 — Alpha). Thus, it can be seen that the common base current linearity will be considerably better than the common emitter or common collector linearity. However, recent improvements in power transistors reduce common emitter gain variations to the point where they are relatively negligible.

Advantage can be taken of the input impedance nonlinearity as a function of signal voltage to compensate for the nonlinearity of the common emitter current gain characteristics, and thereby make the stage more linear. The two nonlinearities cancel in the following manner: at low signal levels the input impedance is high and the input current is low, but the current gain is high at low currents. As signal level increases the input impedance decreases, giving a proportionately larger input current. This input current increase is offset by a current gain decrease, and the overall action makes the transconductance more nearly linear.

Power supply voltage

Selection of a suitable power supply voltage depends on many factors:

1. The transistor's peak inverse voltage rating, which must not be exceeded.
2. Junction temperature and thermal runaway, which are functions of supply voltage. Smaller collector voltages give best thermal stability.
3. Power gain, which increases with increased collector voltage for common base and common emitter configurations.
4. Distortion, which diminishes at higher collector voltages for the same power rating.
5. Specific circuit—for instance, if load appears directly in the transistor's output circuit.

In general, for medium-power operation the use of the highest available collector voltage is advantageous, although for higher power operation the thermal considerations are usually more important.

Load impedance

Load impedance, like source impedance, is not usually a controllable parameter. It must be known, of course, to complete the circuit design. If the circuit uses an output transformer then load impedance primarily affects transformer design. If the load impedance appears directly in the transistor stage's output circuit it influences choice of collector voltage.

Operating temperature range

Operating temperature range, in conjunction with the heat-dissipating arrangement, determines the minimum allowable dissipation rating of the transistor. The associated circuitry may require modified design to improve stability since these thermal considerations determine the maximum allowable stability factor.

Transformers

Transformers in transistor circuits are used in the same way as they are used with vacuum tubes, although there are a number of considerations peculiar to transistor circuitry. Among them:

1. Primary *IR* drop—for many applications this voltage drop can be more serious than the transformer's power losses, because the transistor circuit's relatively low dc supply voltage makes appreciable a loss of even a few volts in the primary.
2. Effect on thermal stability—dc resistance in the base circuit increases the stability factor and thus may subject the circuit to thermal runaway. If this happens, the transformer's winding resistance must be made smaller than is usually dictated by power considerations alone.
3. Leakage inductance—for class B operation it is desirable to have the transformer's leakage inductance as small as possible to minimize switching transients that occur when one transistor cuts off and the other begins to conduct.
4. Core saturation—a transformer driven from a current source, such as a transistor, saturates more easily than one driven from a voltage source. The transformer designer should know the transistor's output impedance to assure an adequate saturation-flux level.

DESIGNING A SERVO AMPLIFIER WITH POWER TRANSISTORS

The servo amplifier is one of the major applications for the power transistor in the control field, and designing a typical servo output stage illustrates basic procedures and points out special features and considerations.

The specifications for the servo amplifier to be designed are:

- Power output to drive servo motor—5 watts at 115 volts rms
- Temperature range—up to 50 deg C
- Power gain—plus 30 db
- Output impedance—less than 2,000 ohms

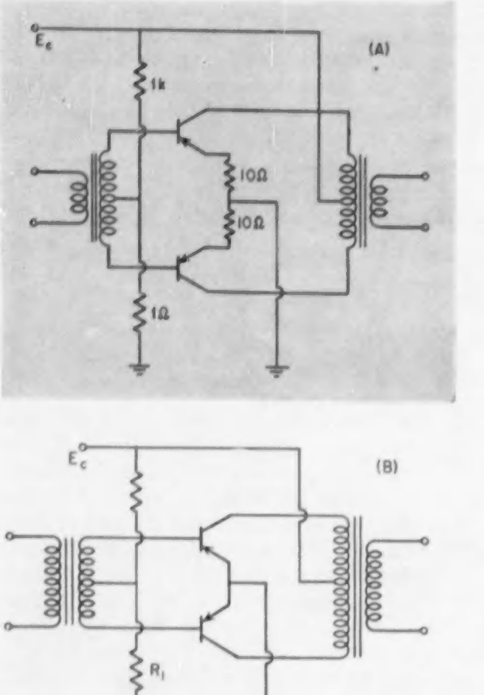


Fig. 7 Two biasing arrangements for output stage, with circuit A preferred because of improved thermal stability.

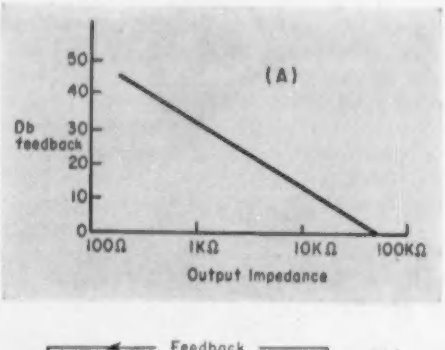


Fig. 8. Voltage feedback reduces output impedance (A), and block diagram (B) shows feedback connection to input of driver stage

- Supply voltage—28 volts

The first design decision involves the configuration. The common base configuration is undesirable from the standpoint of low gain and high output impedance, and though it does give good linearity, in this application linearity is not important. The main disadvantage in driving a servo motor from a high source impedance is that the motor's frequency response narrows. Conventional servo motors, designed to be driven from a voltage (low-impedance) source, suffer when driven from even a moderately high output impedance. Thus, if the servo must be a fast-acting (wide-band) servo the specified 2,000 ohms output impedance would be quite excessive.

This leaves a choice of either the common emitter or the common collector configuration. The common emitter will be selected because of high power gain and moderate output impedance. However, if much lower impedance were required the low-gain common collector configuration would probably be mandatory.

The choice of circuit lies between single-ended class A or push-pull class B. The single-ended circuit saves one transistor and one transformer over the push-pull stage. However, at maximum theoretical efficiency the transistor in a class A single-ended circuit must handle 10 watts for standby condition and 5 watts for full power output condition, while a push-pull class B circuit requires only negligible standby power and dissipates only a 0.7 watts per transistor as full power output. Thus, the class B stage draws much less power from the supply. Also, a quick calculation shows that the heat sink required to dissipate 10 watts at 50 deg C is impractically large. These reasons dictate the choice of the push-pull class B circuit in conjunction with the common emitter configuration.

The next decision involves the transistor type. The high operating temperature conflicts with the need for a reasonably small stability factor, and thus eliminates many transistors that might operate satisfactorily at the specified low dissipation, but that require additional circuit complexity and higher power loss to obtain a small stability factor.

The above reasoning will now be carried out to satisfy the specifications: assume a total thermal resistance of 30 deg C/watt (which requires a heat sink of about 8 to 15 cm in diam depending on the transistor type), and solve the thermal stability equation to determine the allowable stability factor. If 70 percent efficiency is also assumed the transistor dissipation will be 1.1 watts. A typical I_{co} at 30 deg C is 50 microamp. Since:

$$S \times 28 \times {}^{1}/_{18} \times 30 \times 50 \times 10^{-6} \times e^{1/18(1.1 \times 30+18+60-30)} < 1,$$

the solution of this equation yields S < 4. But because a stability factor of four or less is difficult to obtain in a power circuit, stability criteria for thermal resistances of 20 and 25 deg C/watt must be calculated. This results in factors of 8 and 14.

Therefore, to obtain a practical heat sink, design the circuit on the basis of S = 8 and a total thermal resistance of 20 deg C/watt. If a 5-watt transistor such as the M-H H-4 is used, its 14 deg C/watt internal thermal resistance leaves 6 deg C/watt thermal resistance for the heat sink (about 20 cm in diam). But a 20-watt transistor, such as the M-H H-2 with a 3.6 deg C/watt thermal resistance, requires a heat sink of only 10 cm in diam, which is a more reasonable size. Therefore, the H-2 will be selected for this amplifier.

Because the motor requires 115 volts rms at its control winding and the supply voltage is only 28 volts the motor must be driven by a transformer in the transistor's output circuit. (Lower-power motors are now available that can be driven directly from transistors without transformers, and it is expected that high-power ones will be available in the near future.) The output transformer's secondary impedance is 2,600 ohms, as derived from the relationship $R = E^2/P$. Here, P equals 5 watts and E equals 115 volts rms. Assuming an available voltage swing of 26 volts peak (to allow for a 2 volt drop in the transformer and transistor saturation resistance) or 18.2 volts rms, the primary impedance is 67.5 ohms per transistor, as found by reapplying the preceding relationship. However, for the push-pull circuit, the total primary impedance of the center-tapped transformer is $4 \times 67.5 = 270$ ohms, where the factor 4 arises from the second-power relationship between impedance and turns.

Since each transistor in the push-pull circuit sees 67.5 ohms, the 26-volt supply develops 385 ma peak across this impedance. From manufacturer's typical data (not shown) the common emitter current gain Beta, at 385 ma, is about 26.

The transistor's input impedance is the input voltage divided by the input current. This, too, can be found from the transistor characteristics: they show that 385 ma requires 1.0 volts at the input, and under these two conditions the input current is 15 ma. Thus the input impedance equals 1.0/0.015, or 67 ohms. Knowing Beta (26), the load impedance (67.5), and the input impedance (67), the power gain can be calculated from the gain equation for the common emitter configuration. Therefore, the power gain is $26^2 \times 67.5/67$, or 670 (28 db).

In production runs of transistors Beta varies considerably, so that with a low-Beta transistor the power gain is reduced from the nominal value. However, good impedance matching between the input transformer and the transistor's input impedance assures maximum power transfer into the power stage and somewhat compensates for the reduced power gain.

One good way to insure good impedance matching for any range of Beta is to design the transformer to match a higher input impedance, for this case about 120 to 150 ohms. An even better way is to wind the above transformer with taps on the secondary and select the tap that gives maximum power transfer.

The input transformer's primary impedance depends on the allowable voltage swing, which in turn depends on the power amplifier's driving stage. Assume a class B driver with a 5-volt drop in its emitter stabilizing resistor and a 2-volt transformer drop. Then the swing will be $(28 - 7) \times 0.707$, or 14.8 volts rms. Knowing the input power in addition to the rms swing yields the input impedance. Here, the input power equals the output power (5 watts) divided by the power gain (670), which equals 7.5 mw. Thus, the transformer's primary impedance equals $14.8^2/0.0075$, or 29,000 ohms.

If the output stage were to be operated as presently designed, it would be found that its power gain is considerably lower and its input impedance considerably higher than anticipated. This is because of the high transistor input impedance at low currents. This difficulty may be eliminated simply by applying bias to the transistors, thus causing them to operate in a higher-current region. For this circuit the amount of bias is not critical, and here 5 ma is a reasonable value as determined for the condition of minimum crossover distortion.

Figures 7A and 7B illustrate two versions of the final circuit, each using a different biasing method. The circuit in 7A includes an emitter resistance in each half of the push-pull circuit to improve the temperature stability. But this requires that the primary impedance of the output transformer be reduced to compensate for the IR drop of the emitter resistances.

The circuit in Figures 7B has no emitter resistances, making it extremely temperature-sensitive (unless R_1 compensates for changing temperatures). However, even for circuits without compensation the increase in biasing current may not seriously affect overall operation. Thus, a bias current increase to 20 or 30 ma is negligible compared with the 385-ma peak current drawn by the transistor and transferred to the servo motor.

Although the first biasing circuit contains emitter voltage drops and operates with a slight decrease in power gain, its thermal stability is improved. Thus, the circuit in Figure 7A is preferable.

Experimental determination of the output impedance of this circuit without any feedback (zero db feedback in Figure 8A) shows that the impedance is much too great to meet the desired specification of less than 2,000 ohms. But Figure 8A also shows that increasing the voltage feedback reduces the output impedance as a function of the amount of feedback to the point where it matches the motor impedance with respect to power transfer and frequency response. The curve of Figure 8A was taken with the feedback around the output stage and its driver stage, as shown in Figure 8B. Unfortunately, feedback reduces overall gain, but this can be compensated by increasing the gain of the driver stage.

Reset Magnetic Servo Amplifiers

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The Gist: Conventional servo amplifiers are handicapped in high-speed loops by the substantial lag in their highly inductive circuits. The amplifier described here, for a servo displaying zero static and velocity error, uses two lag networks (one in a positive and one in a negative feedback path). It belongs to a new group of circuits called half-wave magnetic amplifiers, which make use of the reset principle and associated circuits to furnish a response time of one-half cycle per stage.

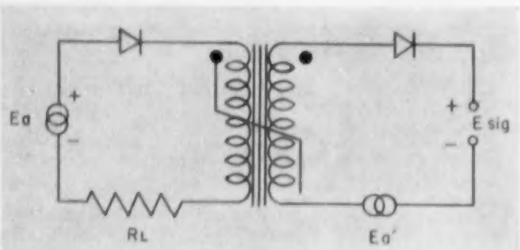

FIG. 1. Basic Ramey circuit resets flux level in reactor with every carrier cycle.

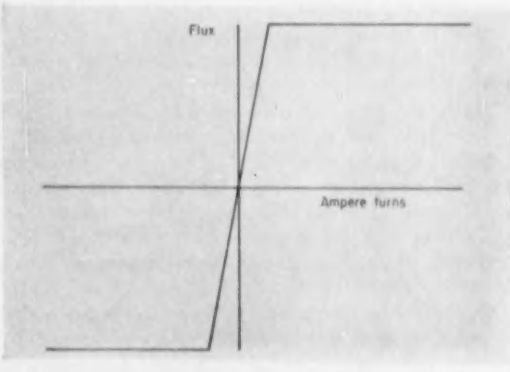

FIG. 2. Simplified B-H curve for the reactor.

Despite such advantages as structural ruggedness and long maintenance-free life, conventional magnetic amplifiers often are unsuitable for precise rapid servos because their response is slow. In many systems, a magnetic amplifier lag of three or four cycles of line frequency would cause instability.

The inductive nature of the control circuit is responsible for the slow response of a magnetic amplifier. The actual control circuit inductance depends on a number of factors, but it turns out that anything that increases the power gain also increases the response time. Hence, those servos that require high speed and gain cannot use the conventional magnetic amplifier.

A family of circuits called half-wave magnetic amplifiers has recently been developed to fill the need for a high-speed magnetic design. The basic unit of these amplifiers is the Ramey circuit, which has a fixed response time of one half-cycle of line frequency. Like all magnetic amplifiers, the Ramey circuit is a carrier-type device. It transmits the envelope of the carrier wave, which is usually the line frequency of 60 or 400 cycles.

Basically, conventional magnetic amplifiers are full-wave devices, while reset magnetic amplifiers are half-wave. The conventional magnetic amplifier uses as its basic circuit a pair of reactors that saturate alternately, one in the postive half-cycle and the other in the negative half-cycle. The control circuit sees both reactors in series, and because they are never both saturated simultaneously, the control circuit always sees a high impedance.

The simple but fundamental contribution by Ramey was a method of separating the functions of flux setting and saturation into alternate half-cycles. The basic circuit consists of a single core with two windings, Figure 1, with a B-H curve assumed as shown in Figure 2.

Suppose there is no signal voltage applied and that at the beginning of the positive cycle the flux in the core is at the negative knee of the curve. The voltage E_a, which is a sine wave at line frequency, divides across the coil and the load resistance. Since the inductance of the coil is very high, most of the voltage is across the coil. To support a voltage drop across a coil, there must be a change in flux according to the relation,

$$e = N \frac{d\phi}{dt}, \text{ or in integral form, } \phi = \frac{1}{N} \int e\,dt$$

Thus, as long as the voltage E_a appears across the coil, the flux must be changing in the positive direction. The reactor is designed so that the flux reaches the upper knee of the curve at the end of the positive half-cycle. During this half-cycle voltage E_a' has no effect because it is blocked by the rectifier. Now in the negative half-cycle, E_a' has a polarity which can drive the flux down in the negative direction, but on the load side, E_a is blocked by the rectifier. Again E_a' is chosen so that the flux just reaches the negative knee at the end of the half-cycle.

Thus, in the absence of a signal voltage, the flux will be driven up and down the curve alternately by the two voltages E_a and E_a'. Since the core is never saturated, the inductance is always high and little current flows in either the load or signal side.

Now suppose a signal voltage is applied in series with E_a' and in the opposing direction. The net voltage across the coil in the negative half-cycle (called the reset half-cycle) is less and the flux does not move down as far.

At the start of the positive half-cycle the flux starts to move up again. However, since its starting point is higher, it reaches the top before the end of the half-cycle. When this happens, the core saturates, the inductance falls to a low value, and the voltage E_a appears across the load resistance. Hence, the voltage across the load in any positive half-cycle is proportional to the signal voltage that existed in the previous negative half-cycle only, and the response of the amplifier occurs within one half-cycle.

Two points are worthy of special notice:

- Power gain is very high, since the control-signal current can flow only when the core is saturated. In fact, since the control signal is always opposed to and smaller than E_a' it does not deliver any power at all to the circuit but absorbs power from it.
- The circuit responds equally well to ac and dc. This can be seen if it is remembered that only the signal voltage that appears during the reset half-cycle is effective in determining the firing angle. Any signal voltage that exists during the forward half-cycle is blocked by the rectifier. The basic Ramey circuit is capable of a large number of variations to meet different requirements. For example, a full-wave rectifier signal can be obtained from two Ramey circuits back to back, Figure 3.

NOL circuit

An amplifier providing a phase reversible half-wave output suitable for servo applications has been developed at the Naval Ordnance Laboratories, utilizing the reset principle. The basic amplifier is shown in Figure 4.

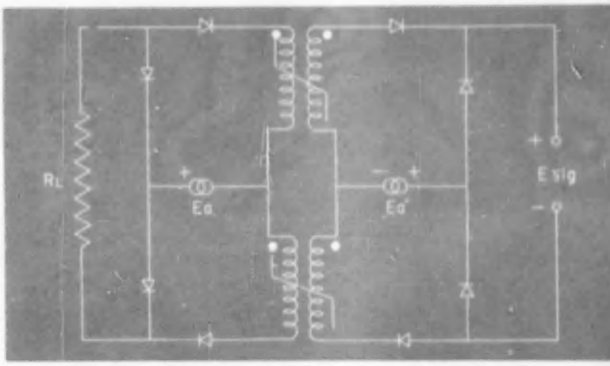

FIG. 3. Full-wave output is attained by a back-to-back circuit.

To analyze its operation, consider the start of the reset half-cycle. Assuming that there is no signal voltage, both cores are at the positive knee of the B-H curve. During the reset period the polarity of the applied ac is opposed to the direction of the rectifiers. The only place that current can flow is in R_r. Notice that each leg of the bridge contains a load winding on both cores. R_r is adjusted so that during the reset period the flux is driven down to a desired point. Since both legs are identical and all load windings have equal numbers of turns, both cores are reset to the same point on the B-H curve.

During the next forward period the flux moves up in the positive direction in both cores, and they both saturate at the same time. When this happens, a large amount of current flows down through both legs. However, throughout the entire cycle identical voltages have appeared at both ends of the load resistance; hence no current flows in it.

Now suppose that during the reset period a signal voltage E_c is applied. The direction of E_c is such as to aid the resetting action in one core and to oppose it in the other. Thus at the end of the reset period one core is lower on the B-H curve than the other.

In the forward period the flux moves to the upper knee and saturation occurs sooner in one core than in the other. During the time that one core is saturated and the other is not, the full line voltage appears across the load resistance. The output voltage is a series of pulses which are sections of the positive sine wave of the line. With increasing sig-

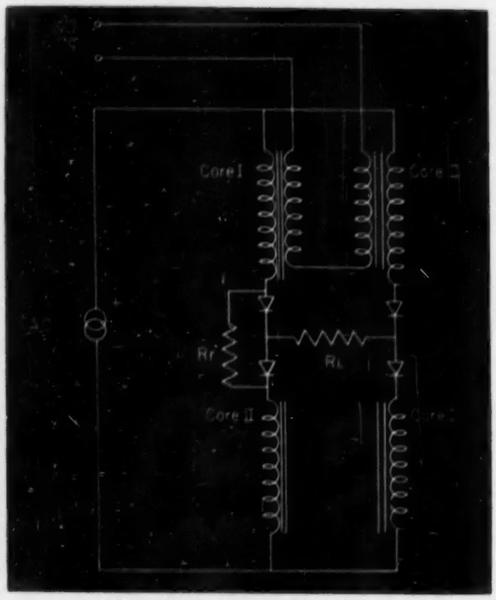

FIG. 4. Naval Ordnance Lab magnetic amplifier has one-cycle response.

nals the pulses become wider. Maximum ouput occurs when the signal voltage causes full reset in one core and no reset in the other. In this case, the output is a half-wave rectified sine wave.

The output pulses of the NOL amplifier are not ideal for driving a two-phase servomotor. They contain a dc component which causes excess heating, and the waveform contains many higher harmonics which do not contribute to useful torque. However, about 80 percent of the rated torque may be realized with this type of signal if the duty factor is not too high, a condition that exists in most servos.

Since the output pulses are half-wave, they contain both a dc component of reversible polarity and an ac component of reversible phase. Thus the NOL amplifier responds to both ac and dc inputs and has an output containing ac and dc, both of which can be made useful. This property can aid in the design of high-performance servo systems.

The output waveform of the NOL amplifier makes it particularly easy to cascade stages. The waveform best suited to effect reset in an NOL stage is a half-wave pulse which occurs only during the reset half-cycle. Since the output waveform is also a half-wave pulse, it is only necessary to make the output period of the first stage correspond to the reset period of the second stage. This is done simply by reversing the rectifiers in the second stage, as shown in Figure 4. The response time of a two-stage NOL amplifier is one cycle of line frequency. In fact, the response time in half-cycles is equal to the number of stages.

Servo compensation

Secondary feedback loops within the amplifier provide servo compensation. Figure 5 shows a proportional amplifier with a negative feedback path incorporating an integrating network. The resistor and capacitor is a voltage divider according to the expression:

$$E_o = E_i \frac{1}{1 + RC(s)}$$

Allowing $RC = \frac{1}{\omega_1}$

$$E_o = E_i \frac{1}{1 + s/\omega_1}, \text{ so that } \frac{E_o}{E_i} = \frac{\omega_1}{s + \omega_1}$$

Placed in the negative feedback path, the entire loop performs according to:

$$\frac{C(s)}{R(s)} = \frac{K}{1 + K\dfrac{\omega_1}{s + \omega_1}} = K\left[\frac{s + \omega_1}{s + (1 + K)\,\omega_1}\right]$$

The expression in the bracket is that of an ordinary lead network. The negative feedback loop thus becomes equivalent to a lead network whose constants can be selected by varying **K and ω.**

It may be necessary to have a preamplifier in front of the loop to increase the overall gain, since in general it is not desirable to have $(1 + K)$ very large. When the constants of such a network are properly selected, the servo is more stable and its bandwidth is extended. The result is a dc-compensated ac servo without choppers, accurate ac stabilization networks, or accurate frequency control.

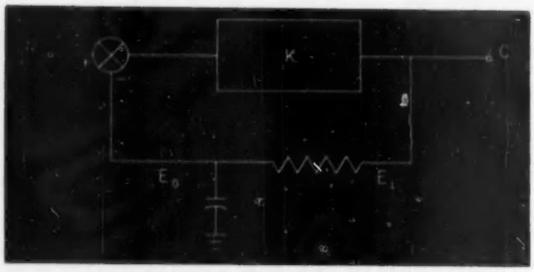

FIG. 5. Servo amplifier with lag network in negative feedback loop behaves like lead network.

Another type of stabilization that can be obtained in NOL servo amplifiers is integral compensation. Figure 6 shows a proportional amplifier with an integrating network in a positive feedback loop. Its transfer function is:

$$\frac{C(s)}{R(s)} = \frac{K}{1 - K\mu\dfrac{\omega_2}{s + \omega_2}} = K\left[\frac{s + \omega_2}{s + \omega_2 - K\mu\,\omega_2}\right]$$

If μ, the attenuation of the network, is made the reciprocal of the gain K, the transfer function becomes

$$\frac{C(s)}{R(s)} = K\left[\frac{s + \omega_2}{s}\right]$$

Thus the transfer function contains a pure integrating term. An amplifier containing such an integrating term has some unusual properties. By itself it is unstable; that is, outside the servo loop it will build up to full output with zero input. In a servo loop, however, it is stable. The servo will

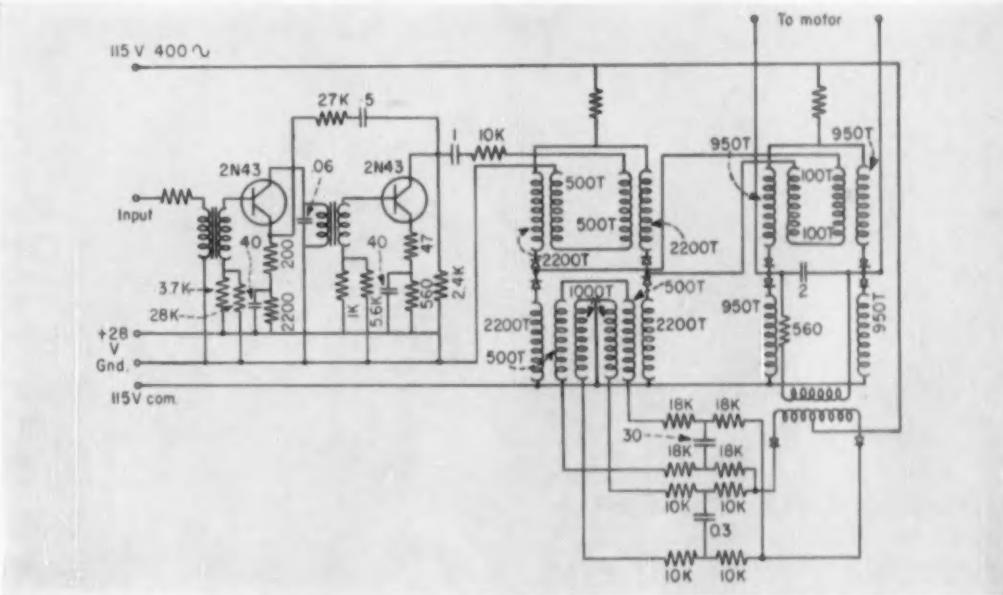

FIG. 7. Two stages of transistor preamplification precede two stages of magnetic amplification, incorporating positive and negative lag network feedback paths.

have zero static error and zero velocity error. The reason for this is that the amplifier has essentially infinite gain for dc signals. Any error voltage, however small, that exists at the input to the amplifier will be integrated until it is large enough to actuate the motor and reduce the error to zero.

Figure 7 shows the schematic of a complete servo amplifier with a two-stage transistor preamp and a two-stage NOL magnetic amplifier. The compensation consists of two feedback loops, which provide both types of control described earlier, lead and integral (or rate and reset, as the process people would say). The transistor preamp has negative feedback to stabilize its gain at a value of 70.

The first stage of the NOL amplifier has two additional feedback windings for control purposes. The output of the second stage is tuned and drives the control phase of a two-phase servomotor. It also drives a demodulator, which provides the polarity-reversing dc for the feedback loops. It would be possible to utilize the dc component of the output waveform directly for this purpose, but the dc resistance of the control phase of the motor is so small that insufficient feedback voltage appears across it. The calculation of the performance of a third-order servo system like this is often more profitably bypassed in favor of a mock-up with the constants selected experimentally.

The NOL amplifier, while it performs well, has one serious disadvantage: its waveform does not permit obtaining rated torque from a servomotor. An output stage which utilizes two NOL stages to obtain full-wave output without sacrificing the control capabilities has recently been described. One stage is used in the conventional manner and is called the master stage. The other stage (called the slave stage) is reset by a portion of the master-stage output pulse and supplies an output pulse during the reset period of the master stage. By this means, full-rated torque is obtained from the motor.

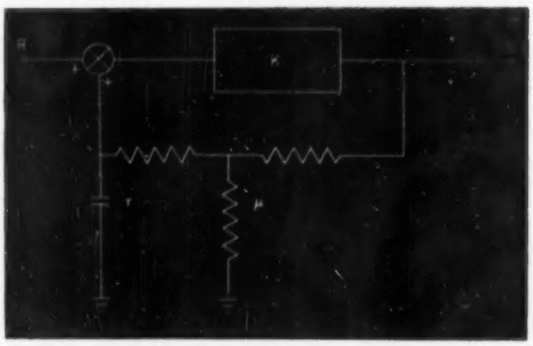

FIG. 6. Servo amplifier with integrating network and attenuator in positive feedback loop is unstable by itself, but reduces velocity error to zero with a servo loop.

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Pneumatic Control of a Turbojet Variable Nozzle

Many operating functions of a turbojet engine perform well when controlled by pneumatics. Author Reed describes one of these functions, the control of a variable-area nozzle. Using all-pneumatic control and actuation he shows:

1. How to automatically adjust the nozzle during afterburner operation as demanded by flight conditions;

2. How to obtain stable control operation; and

3. How to set up interlock functions.

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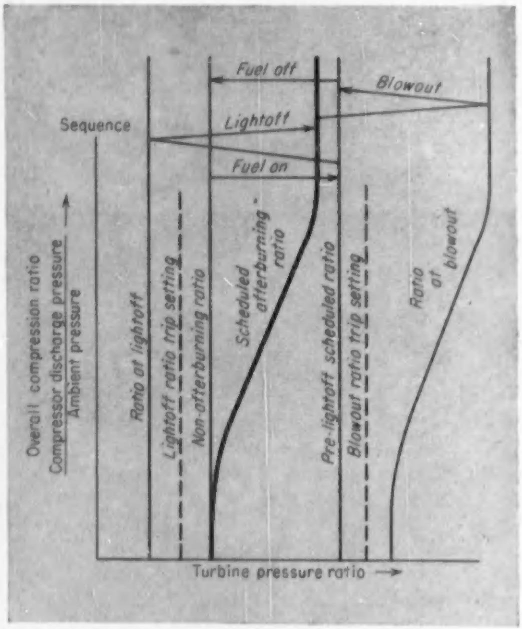


FIG. 1. The relationship between the overall compression ratio and the turbine pressure ratio determines the sequence of operations in the scheduled control of the afterburner and variable-area nozzle of a turbojet engine. Once the afterburner is in operation, the control automatically adjusts nozzle area in accordance with schedule shown by heavy line.

Until a few years ago, only electronics and hydraulics found broad application in aircraft control systems. Today, however, with jet aircraft speeds generating temperatures ranging from 500 to 1,000 deg F, pneumatics have come into their own here, too. The reliability, fast action, and light weight of pneumatic controls and actuators make for favorable operation under these stringent flight conditions.

THE TURBOJET ENGINE

A turbojet engine is a good example of a controllable "process" in an aircraft. Basically, the engine draws air at its inlet, compresses the air, and burns fuel injected into the compressed-air atmosphere. The resulting high-pressure combustion gas impinges on the turbine blades that drive the compressor. The gas, with increased pressure, exhausts through the nozzle. The reaction of the gas leaving the engine creates a thrust, or propulsive force.

Early turbojet engines were designed for use with a fixed-area jet nozzle. This resulted in essentially a fixed turbine pressure ratio. Later, afterburners were added to the engine. In the afterburner, an additional ignition arrangement, the unburned oxygen in the gas leaving the turbine is reignited with additional fuel and forced through the nozzle. The afterburner, being relatively inefficient, is used only when its high thrust—in itself a distinct advan-

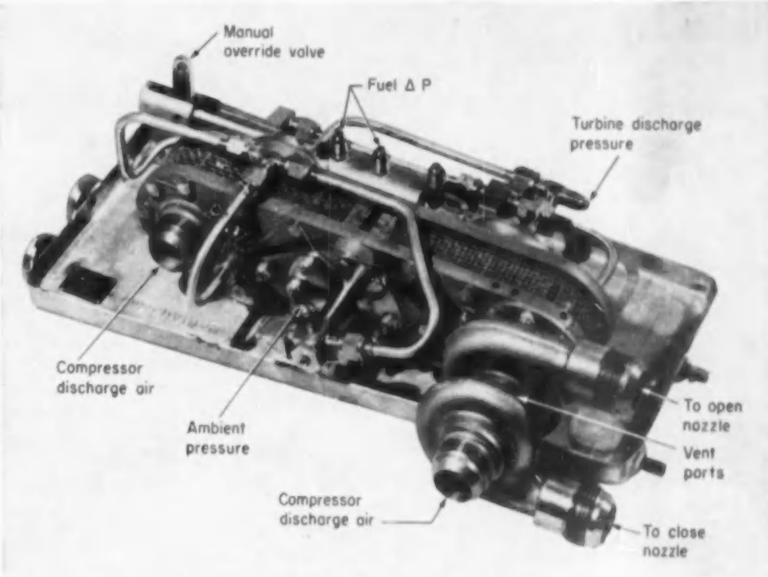


FIG. 2. A combination of three basic pneumatic control elements forms the complete computing and control system to carry out the schedules of Figure 1.

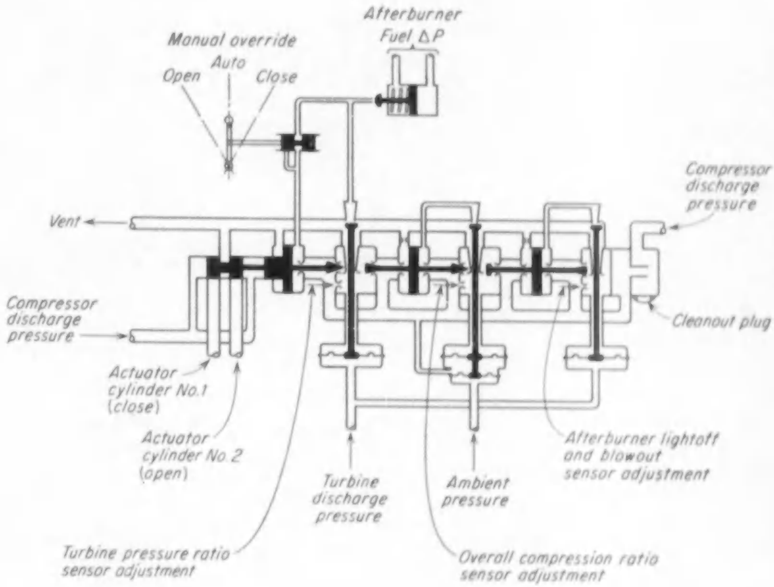


FIG. 3. The schematic view of the control aids in following it as it goes through its functions of controlling the afterburner and nozzle portions of the jet aircraft.

tage—is needed, such as in take-off or in tactical military operations. With the advent of the afterburner it became necessary to vary the jet-nozzle area and thus compensate for the increased volume of exhaust gas resulting from afterburner combustion.

Limiting the operation of a turbojet engine is the fact that the turbine-blade temperature must not exceed a permissible maximum. To assure this requires maintaining constant the turbine inlet temperature. Measuring the inlet temperature is not always practical, and so turbine discharge temperature serves as a universally-accepted yardstick. But maintaining a constant turbine discharge temperature (at constant military rpm as compressor inlet temperature rises) requires an increase in the turbine pressure ratio, accomplished by opening the nozzle.

A variable-area nozzle adjusted in accordance with the turbine pressure ratio can be used to maintain the turbine blades at their maximum permissible temperature. Automatic variable-area nozzle adjustment requires a control system that schedules (this includes computing) the proper turbine pressure ratio for each corresponding flight condition. The following section deals with the control's functions in starting the afterburner and in automatically adjusting the nozzle when the afterburner is operative. A later section discusses stabilization of the variable-nozzle control loop.

THE CONTROL SCHEDULE

The control performs the scheduled functions shown in Figure 1. Most of these functions are of the auxiliary or interlock type. But one of them, marked in the figure as "scheduled afterburning ratio", is of the continuous or modulating type needed to automatically adjust the nozzle's area in accordance with flight conditions.

The overall operation of the control system is as follows:

- during normal (nonafterburning) engine conditions the control closes the nozzle to some minimum area determined by a mechanical stop
- on initiation of afterburner operation the control opens the nozzle to some intermediate area prior to lightoff
- after lightoff the control automatically adjusts the nozzle area in accordance with a predetermined turbine pressure ratio schedule, which is a function of the engine overall compression ratio (see heavy line, Figure 1)
- in the event of burner blowout the control returns the nozzle to the intermediate opening, ready for a subseqent lightoff
- on termination of afterburner operation the control returns the nozzle to the nonafterburning stop

The control system performing these functions can be electronic, hydraulic, or pneumatic, or a combination of these media. In selecting the particular medium adequate consideration must be given to inherent design and environmental problems. The balance of this article emphasizes pneumatic control, in particular the Solar Microjet control.

[In another paper, "A New Approach to Turbojet and Ramjet Engine Control", SAE #612, Oct. 11-15, 1955, the author presents a detailed description of the Microjet control, and discusses other pneumatic control applications, such as overspeed control, engine fuel control, shock position control, and afterburner fuel control. A review of the design and operating principles of the basic control is contained in Table 1.—Ed.]

The pneumatic variable nozzle control that satisfactorily performs the functions listed above combines three basic units, as illustrated in Figure 2. A schematic of this arrangement, such as the one in Figure 3, aids in following the control as it fulfills the following scheduled functions.

Nonafterburning operation

The control includes a fuel-pressure sensing element which overrides all automatic functions during nonafterburning operation and maintains the jet-engine nozzle in the minimum-area position. The differential fuel pressure from the afterburner fuel-metering control is applied to a spring-loaded piston. When the differential pressure is low (no fuel flow) the spring forces this piston to the right and uncovers a flapper valve that reduces the pressure on the right end of the main air-valve piston. The main air-valve piston, which has compressor discharge pressure applied to its left end, is forced to the right. This action uncovers valving ports, admits compressed air to the cylinders of the jet-nozzle actuators, and closes the nozzle to its minimum-area position.

Afterburner ignition

The afterburner lightoff and blowout sensor consists of the diaphragm, orifice chamber, and piston assembly, shown at the right in Figure 3. During nonafterburning operation the turbine discharge pressure (applied to the lower side of the diaphragm) is at a smaller value than that of the reference pressure (applied to the upper side). Thus, the diaphragm is held in a downward position and the flapper valve opens, causing a reduction of the pressure on the right end of the piston. The piston, held to the right, closes one of the inlet orifices in the overall compression ratio sensing section. This biases the overall compression ratio sensor, which as a result of the bias holds its own piston, shown near the center of the drawing, to the left against fixed stops.

When the pilot desires to initiate afterburning he turns on the afterburner fuel pump and the ignition controls. As soon as the differential fuel pressure rises sufficiently, it moves the fuel-pressure piston to the left and closes the flapper valve. This is the first step in the automatic control of the jet nozzle. Since the compression ratio sensing element is locked in a fixed position during nonafterburning operation, the turbine-pressure-ratio-sensing element opens the jet nozzle to an intermediate area before ignition to prevent possible engine damage by compressor surge.

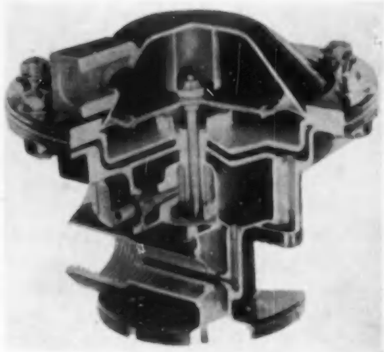
Afterburning operation

When the afterburner ignites, the turbine discharge pressure rises sharply to a value greater than the preset reference pressure in the afterburner lightoff and blowout sensing element. The pressure increase displaces upward the diaphragm of the afterburner lightoff and blowout sensor, closes the flapper valve, and displaces the piston to the left. As the piston moves it resets the reference pressure to a smaller value so that the diaphragm remains in the upward position, even after the turbine pressure ratio has been restored. This reset action returns the compression ratio sensing element, following afterburner ignition, to normal automatic operation.

During afterburning the turbine-pressure ratio sensor automatically adjusts the variable nozzle according to the predetermined turbine-pressure ratio established by the corresponding value of overall compression ratio, as shown by the heavy line in Figure 1. Thus, if the turbine-discharge pressure rises, the diaphragm of the turbine-pressure-ratio sensor moves upward and closes the flapper valve. Therefore, the piston moves to the left, increases the

Table 1

HOW THE PNEUMATIC CONTROL WORKS



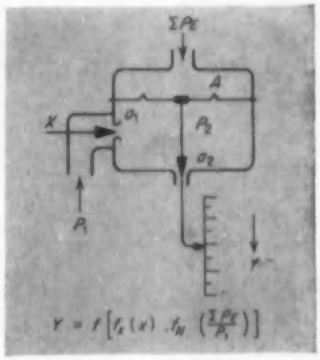


Figure A is a cutaway view of a single-element Microjet control, the operating principles of which are shown in the simplified drawing in Figure B. Since the primary purpose of the control is to yield a mechanical-displacement output signal proportional to the ratio of two pressures, one of these pressures is applied above the flexible diaphragm and the other is used to generate a reference pressure below it. Air, bled from compressor discharge in a jet engine, generates the reference pressure through two series orifices. The area of one orifice is controlled by a contoured needle attached to the diaphragm.

The flexible diaphragm operates in response to pressure difference to maintain the reference pressure exactly equal to the pressure applied above the diaphragm. An increase in upper pressure causes a downward diaphragm movement and because of the tapered needle, creates a decrease in the area of the second orifice. This area decrease raises the reference pressure and retards diaphragm movement until equilibrium is restablished. Thus, the diaphragm has been displaced to a new position at which the two pressures are equal, and this new position is directly related to the new ratio of the two pressures. Many jet-engine operating parameters depend on the ratios of two pressures; thus this device fulfills necessary engine-control functions. The control of the variable-area nozzle, the function discussed here, depends on the ratio of turbine discharge pressure and compressor discharge pressure.

The general equation describing the operation of this pneumatic control is:

$$Y = f\left[f_X(X) \times f_N\left(\frac{\Sigma P_E}{P_1}\right)\right]$$

which states that the output displacement (Y) is a function of the product of the pressure ratio function $f(\Sigma P_E/P_1)$ and the input displacement function $f_X(X)$. Here, ΣP_E represents the sum of all applied pressures, including pneumatic and mechanically applied forces. In general, then, the equation relates the output to two independent functions, which, depending on needle contouring, allows a great variety of computations.

When this device is used with a null-balance system to control a variable area nozzle, the general equation reduces to the form:

$$K_Y = f\left[K_X \times f_N\left(\frac{P_{TD}}{P_{CD}}\right)\right]$$

where turbine pressure ratio is maintained constant at a value K_Y determined by a fixed adjustment $K_X = f_X(X)$, and where P_{TD} is turbine discharge pressure and P_{CD} is compressor discharge pressure.

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reference pressure, and restores the diaphragm to the neutral position. As the piston moves, the actuator air control valve shifts to the left, admits air to the jet nozzle actuating cylinders, opens the nozzle, and thus returns the turbine-discharge pressure to the command established by the schedule contoured onto the needle of the control.

Blowout, shutdown, and override

If the afterburner blows out, the afterburner lightoff and blowout sensor detects a turbine-discharge pressure of less than the preset reference pressure. The resulting downward movement of the diaphragm opens the flapper valve, moves the piston to the right, and again locks the compression-ratio sensor in a position that calls for intermediate-area position of the jet nozzle. The engine is then automatically ready for another ignition.

Putting the throttle in the nonafterburning position turns off the fuel and deenergizes the fuel-pressure-sensing unit. This overrides all automatic functions and returns the nozzle to the minimum-area position.

An emergency manual-override valve (Figure 3) permits the pilot to select either full-open, full-closed, or automatic-control conditions for the jet nozzle. Thus in the event of failure of any portion of the automatic control (except the main actuator air control valve), the pilot can still operate the nozzle full open or full closed.

ALL-PNEUMATIC CLOSED-LOOP CONTROL—WITH STABILIZATION

With the afterburner going, the pneumatic control, nozzle-actuator valve, actuator cylinders, and adjustable nozzle operate as a modulating closed-loop system. The control senses the overall compression ratio, computes the required turbine pressure ratio, and moves the servo valve. This, in turn, drives the cylinders open or closed to obtain the turbine pressure ratio commanded by the control. Any deviation from the command, or any new command determined by a new flight condition, automatically adjusts the nozzle to the appropriate opening.

Figure 4A shows the block diagram for the closed-loop variable-area control system shown in Figure 4B. The control medium for this system could be electronic, hydraulic, or pneumatic. In this case, it will be pneumatic. The problem resolves itself into finding the transfer functions and their numerical values, analyzing the system by frequency-response techniques, and adding any pneumatic stabilization that might be necessary to obtain satisfactory control. The linearized (assuming only small changes from the set-point) block diagram is shown in Figure 5.

Electronic and hydraulic forms of actuation are familiar in control of variable nozzles and present no severe stability problems. But pneumatic systems, even with their many inherent advantages, contain certain aspects of instability, particularly when using a pneumatic piston-cylinder actuator.

The piston-actuator in pneumatic systems presents a difficulty with resonant frequency and damping

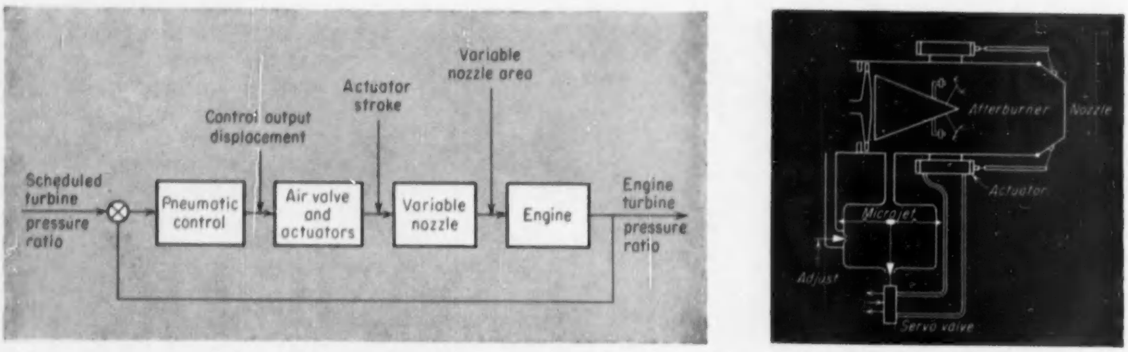
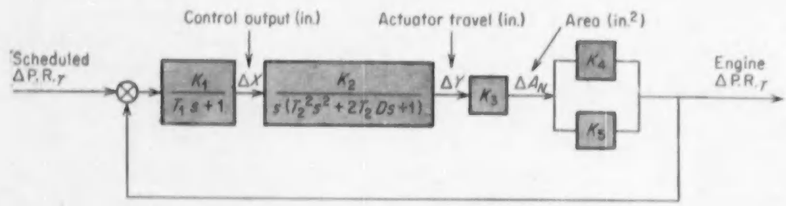


FIG. 4. Once the afterburner is functioning, the system operates closed-loop as shown in Figure 4A. Figure 4B shows the arrangement of system components from which the block diagram is derived.



$\Delta P.R._T$ Change in turbine pressure ratio

K_1 Control gain - (in. displacement / $\Delta P.R._T$)

T_1 Control time constant (seconds)

K_2 Integrator gain - actuator velocity per unit valve motion (in.^{2}/sec/in.)

T_2 Nozzle and actuator mass-spring time constant (seconds)

D Damping factor (dimensionless)

K_3 Variable nozzle gain - area per unit actuator travel (in.^{2}/in.)

Change in turbine pressure ratio due to change in nozzle area

K_4 Effect on compressor discharge pressure - $(\frac{1}{in.^2})$

K_5 Effect on turbine discharge pressure - $(\frac{1}{in.^2})$

FIG. 5. Here the block diagram of the system contains appropriate transfer functions that aid dynamic analysis of operation and stability.

that is characteristic of these systems. The difficulty is rare in hydraulic systems because there the hydraulic fluid's high bulk modulus produces a favorable resonant frequency about two decades higher than the crossover frequency of the loop in which it is applied. Furthermore, leakage and damping due to high viscosity hydraulic fluids limit resonant amplitudes. In pneumatic systems, however, the resonant actuator-load frequency is considerably lower, due mainly to the compressibility of the air, and there is less damping than in comparable hydraulic systems.

In Figure 5 the appropriate transfer functions have been inserted into the blocks. The performance requirements of the variable-nozzle control system is determined, to an extent, by another aircraft control: the fuel-speed control system. By making the crossover frequency of the variable-nozzle control about ten times greater than that of the fuel-speed system, any afterburner disturbances are corrected by the variable-nozzle control and are not reflected into the fuel control. Typical fuel-speed control loops have a crossover frequency of about 1 rad/sec; this requires an overall nozzle-loop crossover frequency of 10 rad/sec. Stated another way, the time constant of the nozzle loop should be some ten times less than the basic fuel-rotor time constant.

Frequency-response analysis

The frequency-response plots of the system depend on certain assumptions and typical numerical values. These are listed below:

1. The nozzle has a low value of viscous damping and presents no variation in load with changing position. (Higher damping and a load gradient are not undesirable, but do complicate analysis).
2. The pneumatic Microjet control can be approximated to a high degree of accuracy by a single-order lag: $K_1/(1+T_1s)$. Here T_1 equals typical values of 0.005 sec at sea level and 0.01 sec at 50,000 ft altitude, and the control gain K_1 equals 0.2 ft/ΔPR.
3. The mass of the actuator and load is 7.0 slugs.
4. The total area A of the actuator pistons is 0.9 ft.^{2}
5. Actuator stroke is 1.00 ft.
6. Total temperature T_o of air to control valve is 800 deg F.
7. Total air volume V_o in actuator and lines is 1.20 ft^3.
8. Nozzle area to actuator displacement, gain K_3, is 0.24 ft^2/ft.
9. Pressure ratio to nozzle area gain, K_4+K_5, (which includes effects of compressor discharge pressure and turbine discharge pressure) equals 1.8ΔPR/ft^2.

The only transfer function not yet known is the valve actuator shown as the second block in Figure 5. The derivation of this transfer function is explained, in Table 2, and the function itself repeated here:

Table 2

VALVE AND ACTUATOR TRANSFER FUNCTION

In terms of its physical parameters

The differential equation of the valve and actuator, from which the transfer function (in Laplace transform terms) is obtained, is found by:

1. Equating all forces acting on the actuator cylinder to the product of the actuator area and the difference in pressures in the two chambers of the actuator.

2. Differentiating the equation found in 1.

3. Finding the rate at which the weight of air flows into and out of the chambers as a function of the valve opening.

4. Substituting the equations found in (3) into the differential equations of (2).

The differential equation found in (4) is then rearranged and solved for the ratio of output to input, which yields the transfer function of the valve-actuator combination:

$$\frac{X(s)}{Y(s)} = \frac{K_2}{s(T_2^2 s^2 + 2\,T_2\,Ds + 1)}$$

for an effective spring rate of load equal to zero as given in Assumption 1 in the text.

Where:

$$K_2 = \frac{RT_oK_o[2L - X_O\,(1 + K_L)]}{A\,P_O[L(1 + K_L) - 2K_L X_O]}$$

$$T_2^2 = \frac{2M\,X_O(L - X_O)}{A\,P_O[L(1 + K_L) - 2\,K_L\,X_O]}$$

$$2\,D\,T_2 = \frac{2\,R_x\,X_O(L - X_O)}{A\,P_O[L(1 + K_L) - 2K_L\,X_O]}$$

$$D = \sqrt{\frac{X_O(L - X_O)}{2MA\,P_O[L(1 + K_L) - 2K_L\,X_o]}}$$

and:

X = actuator displacement, ft
Y = valve displacement, ft
s = d/dt or jω
K_2 = steady-state gain of valve and actuator
T_2 = time constant of valve and actuator, sec
D = damping factor
R = gas constant
T_o = air temperature, deg R
K_o = 0.53 $P_ob/T_o^{1/2}$
L = maximum actuator stroke V_o/A, ft
X_o = initial piston stroke, ft
K_L = load factor F_L/AP_o
A = total actuator area, ft^2
b = width of valve opening, ft
F_L = steady-state load, lb
P_o = supply pressure, psfa
M = mass of actuator piston and load, slugs
R_x = viscous damping of piston and load, lb-sec/ft

$$\frac{X(s)}{Y(s)} = \frac{K_2}{s(T_2^2 s^2 + 2T_2 D s + 1)}$$

where X equals actuator stroke
Y equals valve stroke
K_2 equals the steady-state gain
D equals the damping factor
T_2 equals the time constant, and
s equals d/dt, equals $j\omega$

Table 2 shows that the time constant and the damping vary with actuator stroke and altitude. However, at any given altitude they are greatest at one-half the maximum stroke. This condition will be used in plotting the frequency response of the system at sea level and at 50,000 ft. The compressor discharge pressure decreases with an increase in altitude, and thus decreases the system's supply pressure P_o with altitude. Therefore, based on the values listed above, the time constant and damping factor (at ½ max actuator stroke) can be computed and tabulated for the two altitudes:

P_o(psia)	T_2	D
150	0.0145	0.10
30	0.0325	0.23

Figure 6 shows two plots of the open-loop transfer function, one at sea level (150 psia compressor discharge pressure) and one at 50,000 ft (30 psia). In order to have a 10 rad/sec crossover frequency the total steady-state gain must equal 10. With the overall gain and the other individual gains known, K_2, as calculated, equals 115 ft/sec/ft.

Figure 6 shows that the system's resonant frequency, with a relatively low damping factor at sea level conditions, gives a satisfactory phase margin of 85 deg, but a gain margin of only 3 db. This damping factor, although only 0.1, represents a pneumatically-created 100 lb/ft/sec pure viscous damping force. To obtain this amount of damping force in the pneumatic actuator would be impractical for several reasons: for one thing, it represents wasted energy of about ½ horsepower; for another, the mechanical design becomes difficult and the damping changes with temperature. Obviously, some other method of pneumatic stabilization must be found to limit resonant amplitude of actuator and load, and make the system more stable.

The simplest approach is to use supplementary feed-back around a portion of the loop, as shown in block diagram form in Figure 7. Here, acceleration (second derivative of nozzle displacement) feedback modifies the internal actuator loop and produces a higher break frequency and greatly increased damping. The supplementary damping yields a new set of

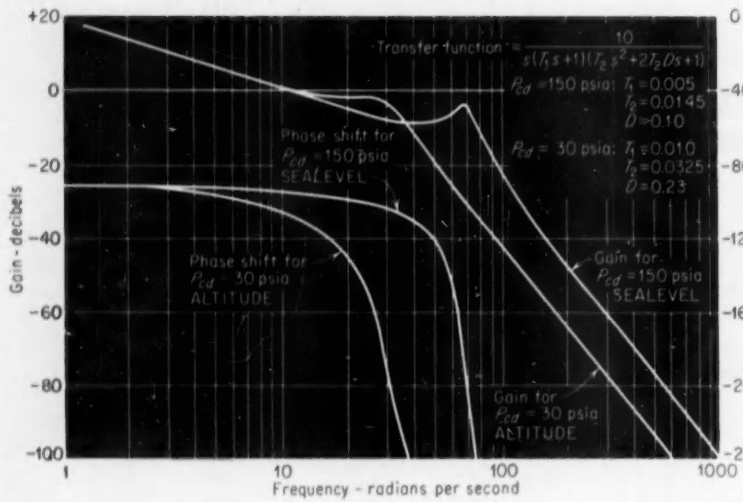


FIG. 6. Without auxiliary damping, the variable-area nozzle control exhibits a resonant peak and a gain margin of only 3 db. This is unsatisfactory because a change in temperature may decrease the actuator's pneumatic damping and cause the system to become unstable.

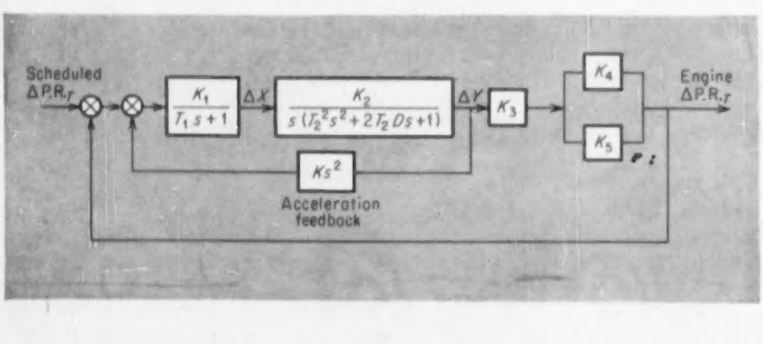


FIG. 7. A supplementary loop with acceleration feedback improves stability and increases effective damping to minimize resonant peaks.

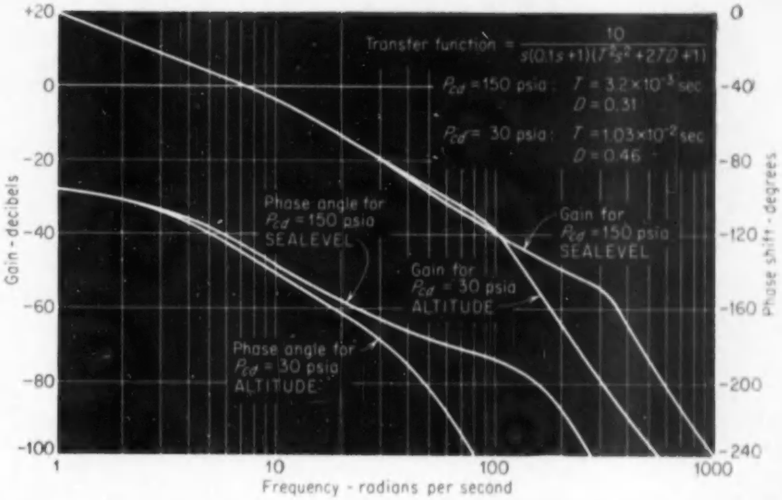


FIG. 8. When supplementary feedback is applied to the basic control loop, the added damping improves stability (compare the above improved gain margin with the frequency response plot of Figure 6).

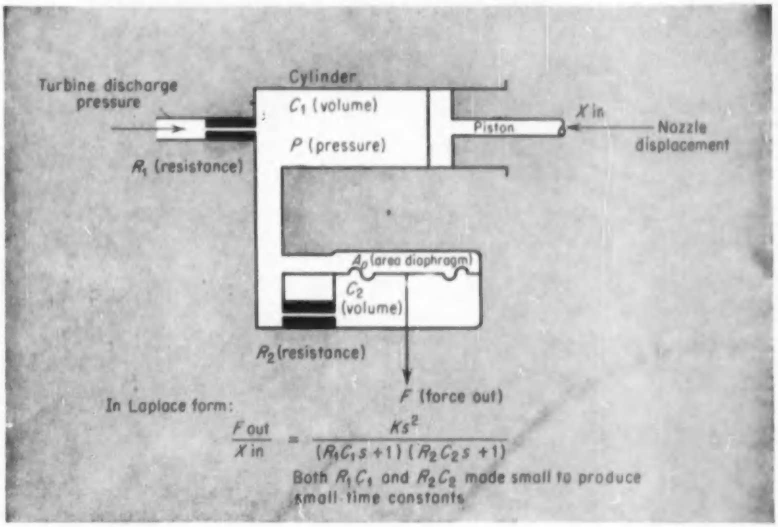


FIG. 9. This pneumatic device differentiates the nozzle displacement twice and gives the pneumatic feedback signal needed to obtain the stability shown by the frequency-response plot of Figure 8.

frequency response plots, as shown in Figure 8, with a cylinder damping factor of zero. For the sea level case, the crossover frequency is approximately 8 rad/sec with a 50-deg phase margin and a 33-db gain margin. These characteristics indicate a stable loop with crisp response.

The altitude case provides very acceptable performance; particularly since the basic fuel-speed time constant increases with altitude.

Pneumatic stabilization

Realizing the necessary stabilization in an all-pneumatic control system requires a pneumatic signal, and Figure 9 illustrates one method of obtaining it. Here, the piston is attached to the jet nozzle so that the pressure inside the upper part of the unit is proportional to the nozzle velocity on opening or closing. The velocity pressure generated in the piston is fed to a diaphragm assembly, where it is differentiated and produces a force proportional to nozzle acceleration. This force is applied to the control's error comparator. Not only does this device increase the damping of the system, without expenditure of useful energy and with a minimum of mechanical difficulty, but it also minimizes the effects of transient disturbance in the control loop.

The device shown in Figure 9 has turbine-pressure ratio connected as the source pressure, and the output assembly installed in the turbine-pressure ratio error-sensing element. Using turbine discharge pressure permits simple mechanization.

Pneumatic hookup

The final arrangement of the pneumatic components and the piping on the jet engine are important in obtaining system stability and fast response. The shortest possible routing of lines effectively eliminates dead time. Keeping out unnecessary fittings, restrictions, and storage volumes reduces the magnitude of piping lags. If these factors, dead time and piping lags, are not minimized their dynamic effects must be included in the closed-loop analysis of the system, particularly when the application demands high quality servo performance.

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Programming Business-Data Processors

THE GIST: The same general procedure is followed in programming both scientific[1] and business problems, although the latter are much larger and more complex. It requires from one to 15 volumes to define a business problem, each volume containing about 200 pages of printed material and 50 charts. Reduced to computer code, a typical problem consists of between 60,000 and 80,000 single-address instructions, split into 80 to 100 individual "runs". Between five and 30 man-years may be required for the analysis, definition, and programming of a large problem.

Defining and programming a scientific problem rarely requires more than the originator and a programmer; sometimes they are even one and the same person. In contrast, the study-team defining a payroll may consist of ten men, and these must consult with twenty or thirty others, mainly department heads and supervisors. The programming and coding group may include twenty people. Communications become complex, and definitions of standards and programming techniques, not required in the intimate communication between scientist and programmer, become necessary.

Dr. Hopper shows the magnitude of the problem and the cooperation requirements by carrying a simplified inventory control system through the five phases of program preparation.

GRACE MURRAY HOPPER
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There are five phases in preparing a business-data-processing problem for computer solution: analysis and definition, programming, coding, debugging, and running. The planning of each phase requires information about all other phases. Figure 1 shows the flow of work and the necessary feedback paths. There are five groups of personnel involved: four directly involved in preparing the problem for computer solution, and one, made up of department heads and supervisors, making sure that the computer procedures will satisfy the requirements of the business operation.

Before considering the preparation of a program, it is best to obtain a picture of the overall procedure by defining the scope of each phase:

▶ *Analysis and Definition*—includes preparing a complete report on all present procedures, examining these procedures in the light of the abilities of electronic data-processing equipment, and changing them to obtain more information or more efficient computer processing. The output of this phase consists of written descriptions of those procedures and of the input data and the required output data, process charts of the data flow, and definitions of the controls that monitor the information for completeness and accuracy. These documents correspond to the equations describing a scientific problem.

▶ *Programming*—includes reducing the problem description and process charts to flow charts, adding provisions for reruns and debugging, defining operating conventions, reducing the input-data descriptions to tape item designs and the output-data descriptions to editing formats, and describing in detail such control procedures as tape-label designs, sentinel conventions, and error treatment.

▶ *Coding*—involves translating the detailed flow charts into computer instructions.

▶ *Debugging*—consists of checking out the programmed runs on the computer, first with simulated data, then with actual data, and finally as an entire system.

▶ *Running*—consists of the day-to-day operation of the problem; this includes reports on inefficiencies, unanticipated variations in the data, and any other unusual behavior of either the problem or the data.

Analysis and definition

To see how the five phases apply to a typical problem, assume that an electronic digital computer is to be used for "inventory control" in a manufacturing concern. The first step is to maintain the inventory balances. Each balance must consist of at least a product identification and a quantity. The system might receive such

information as: shipments, new products to be added, old products to be deleted, receipts from manufacturing, and adjustments and corrections. Each item of change information must identify the product to which it applies, and state the kind of action to be taken and the quantity affected, Figure 2.

Immediately, several more decisions must be made: Are the balances to be maintained on-line or on a cyclic basis? What is the time period of the cycle? How are shipments reported by the shipping department? In what form? And how will the reports be processed and delivered to the computer? What is to be done when (1) the action indicated is "shipped", but no match can be found for the product identification and the change entry is sent to the error list? or (2) when the action indicated is "shipped" and the inventory balance shows a negative quantity? How is the correct information obtained from the shipping department and entered into the system?

After all of the definitions and operations required by Figure 2 have been set up, evaluated, altered, corrected, and checked, only one provision has been made; that is, information is available to the computer to maintain current inventory balances. The next stage of analysis must define the additional processing and reports that are required. It will probably be decided to include not only simple inventory balances, but also information concerning products "in process" and "back ordered". Means must be set up for issuing manufacturing orders when balances are reduced. The information supplied by the shipping department is no longer sufficient; the orders themselves must enter the system. Figure 3 shows the problem at this expanded stage. Provision has been made for more information to enter the system and for more to be drawn off. The inventory balance item has been expanded; in addition to product identification and

FIG. 1. The flow of work and feedback paths involved in preparing a business problem for computer solution.

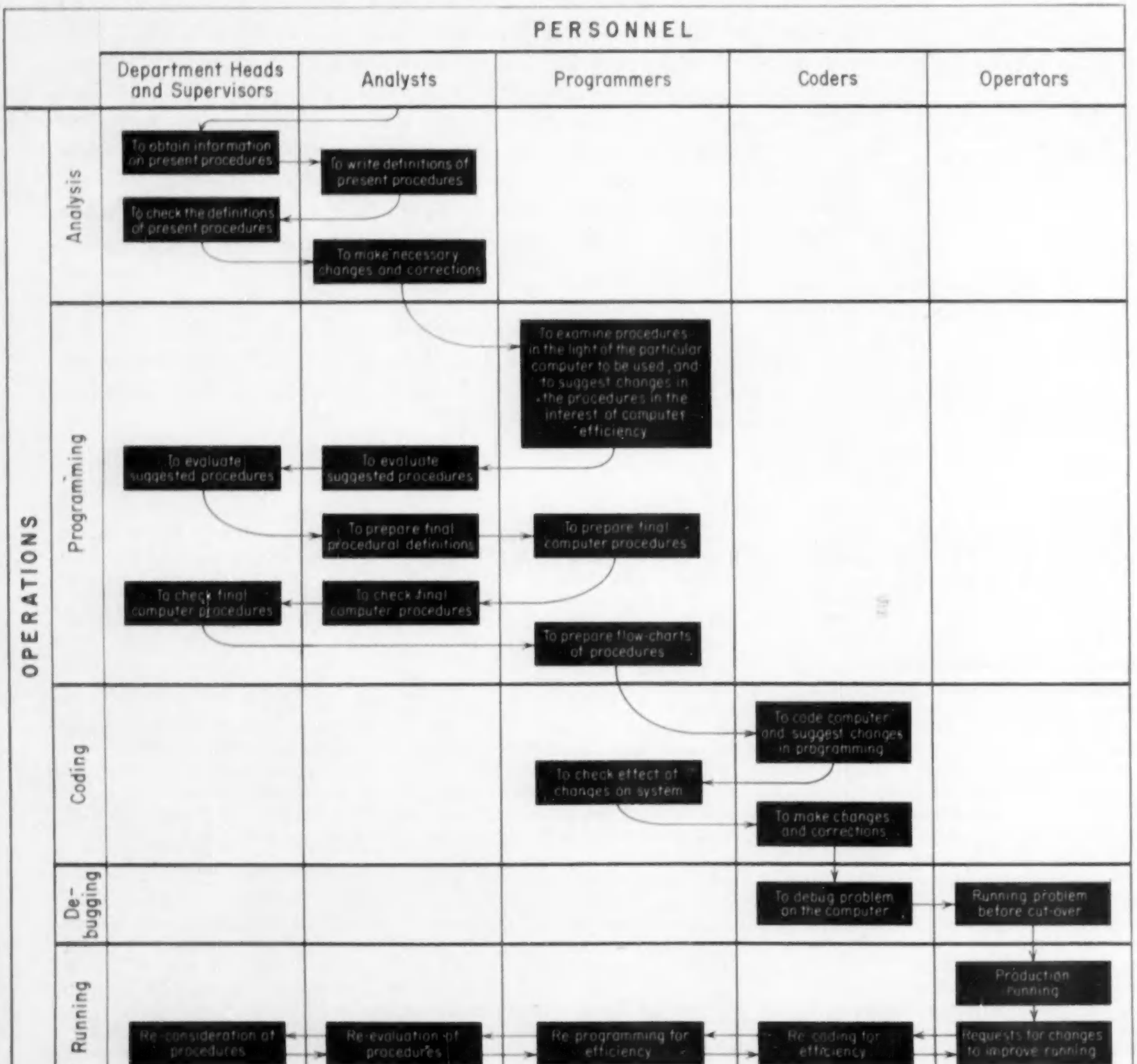


FIG. 2. Preliminary flow chart of an inventory control problem. No decisions or reports are made; information is simply available to the computer.

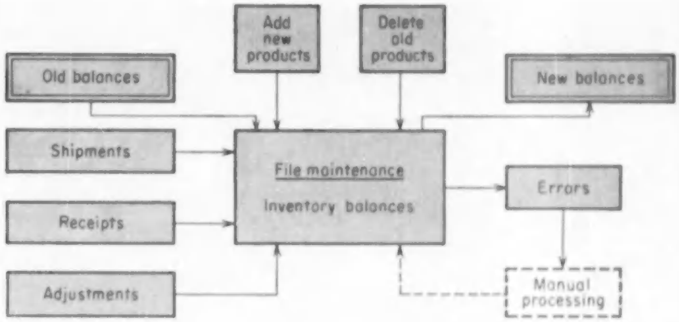
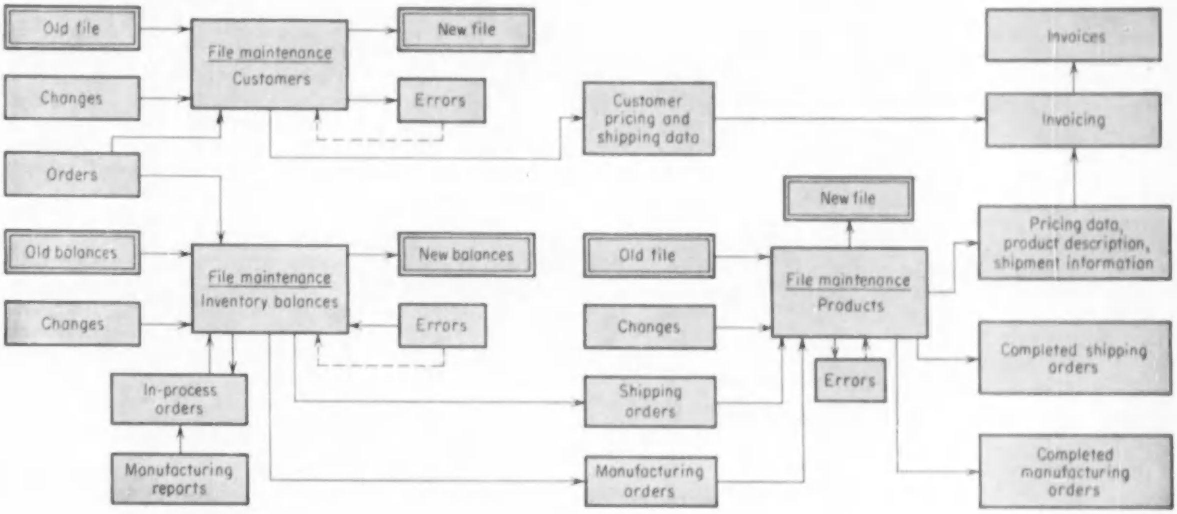


FIG. 3. Expanded flow chart, including two more files. More information is supplied to the system, and more information is delivered.



quantity on hand, it must now include quantity on order and quantity in process and some type of reorder-point information. Two more "files" have been added: "customers" and "products", each requiring file maintenance processing.

It can be seen that each functional operation added into the system means new files to be maintained and frequently expands the amount of information that must be carried in each entry of the basic files. Sales statistics require tabulation of orders by customer, by geographical area, or by comparison with previous sales record files, and demand more information in the customer file.

It is clear that a single process flow chart cannot include sufficient detail to describe the problem. Thus, the problem is divided into parts, each part usually centering around a file-maintenance run, and the chart of each part then expanded in detail. The input and output form of each operation is completely defined and checked with the input and output of connecting operations. Constant reference must be made throughout to the overall process chart to make sure that the segments will ultimately fit together. At the same time, each process and operation must be defined in the finest detail. The definition must include not only the normal treatment of valid data, but also the procedure for handling abnormal cases and for detecting and treating invalid data.

A reexamination of Figure 2 shows that check digits or related techniques must be used to make sure that valid product identifications are received and to check quantities entered by carrying totals. Procedures must be defined for reporting thefts, returns, and catastrophes to the adjustment information. The basic assumption must be made that "anything that can happen, will happen", and the computer must be given a course of action under all circumstances.

The analysis and definition phase is complex even if the existing system is well-formalized: information previously received and checked by human beings reading documents must now be transcribed to magnetic tape, either directly or via punched cards. And if punched cards were used in the past, redesign may show that it is desirable to carry more or less information through the processing.

Where an electronic computer replaces an existing mechanized installation, the obvious move is to simply transfer the existing procedures onto the computer. Thus, the computer can be made to imitate, in turn, a verifier, a sorter, a tabulator, and a collator. But while this may make for quick conversion, it falls short of fully exploiting the abilities of the computer. Suppose that to produce a certain report, the data must be sorted before they can be tabulated. The mechanized procedure would call for a sort run followed by a tabulating run, thus requiring that *all* data be treated twice. But if the pertinent data for each item are extracted from the complete item during the first pass of the sort run, before the sort is initiated, the sorting can be applied to fewer items, and less reading and writing would be required. The data can be tabulated on the last pass of the sort. The size of a punched card is invariable, and a sorter sorts and a tabulator tabulates, but a large computer can handle items of any size and is capable of a diversity of opera-

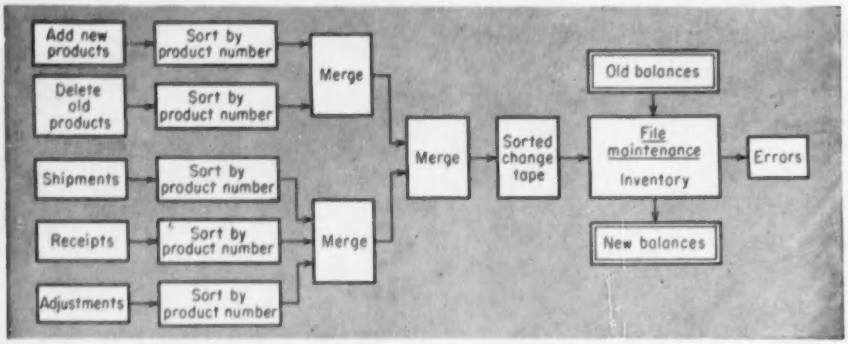


FIG. 4. Programmers expand Figure 2 to start planning the actual data-processing operation. Any changes in basic system function must be checked by analysts.

tions. To obtain the best from a computer, methods and procedures must be reexamined and redefined to take advantage of its unique abilities.

Programming

Programming can begin when the process charts, input and output descriptions, and processing descriptions are available. The previous work required knowledge of the problem—of the particular application. Now a thorough knowledge of the computer is required. For this reason, it is best to assign the tasks of analysis and definition to personnel trained in the methods and procedures of the particular application, and the task of programming to personnel trained on the particular computer to be used. This procedure yields the next feedback loop in problem preparation. As the programmers alter Figure 2 to produce Figure 4, it is necessary for them to check all changes and suggestions with the analysts.

When the programmers complete the detailed process charts showing all of the runs, they must next describe the coding that is to be done. These descriptions fall into two classes:

1. runs requiring detailed flow charts
2. runs using previously coded routines, and requiring "specifications" and flow charts of new segments only

If a computer has been in operation for some time, there usually exist tested and checked sorting routines and a "sort generator". Then it is only necessary for the programmer to specify, for example, the "4-way, 10 word" sort routine. A handbook supplies the information that the routine "sorts 12,000 ten-word items into ascending sequence, using the first 24 digits of the item as the key and requires 10 tape units", that the operation requires approximately 28 min (on UNIVAC I), and that the form of tape labels and tape sentinels assumed must be specified.

If, on the other hand, the programmer *thinks* the input data is already in order, he can select a routine that will perform a sequence check, correctly inserting any items found to be out of sequence, and that in the same run will accept an additional section of coding to perform a checking or editing operation. In this case, the programmer supplies a flow chart of the checking or editing operation, together with the specifications for the standard routine "Sequence Check and Sort".

Finally, if the programmer requires a specialized sort routine, he can supply specifications such as item size and positions of key words to the sort generator. The generating routine then produces the particular routine required for the special case together with its rerun and operating instructions.

Where there is no standard routine, the programmer can probably use standard parts of routines (subroutines), such as those designed for tape handling. For example, in planning a file-maintenance routine, the first flow chart may show all of the tape controls in three or four boxes with word descriptions and references to the corresponding detailed charts. This preliminary chart shows only the logic of the data handling, and refers to subcharts for the processing subroutines. Figure 5 shows a preliminary step in creating the required flow chart.

A word of warning at this point. The charts and diagrams shown in the figures have been over-simplified and skeletonized to illustrate, within the limitations of this article, a step-by-step procedure rather than any actual situation.

Figure 6 shows Figure 5 after symbols are assigned and programming is subdivided. Charts similar to this, together with item designs for input and output, are turned over to the coder for translation into computer coding. At this stage the documentation of the problem extends from the large overall process chart, Figure 3, to the symbolic flow charts of the subroutines, Figure 6. It includes a complete description (in English) of the processing and of all procedures relative to the production and assembly of the input and output data, and instructions for the treatment of inaccurate or incomplete data and all abnormal cases.

The programmer must compromise between speed and storage capacity in defining the runs required to accomplish the desired operations. Good programming, which implies carefully balancing the work to be performed in a particular run against the quantities of data to be read, leads to a successful computer installation. Poor programming, with many tape-limited runs, exceptions treated manually and reinserted, etc., can make the best computer uneconomical. Too often the failure of a computer to meet expectations is blamed on the computer, and, conversely, sometimes praise for a successful operation is heaped on the computer alone. The programmers and the programming should share both the blame and the praise.

Coding

In coding the runs and subroutines, it becomes clear that business problems involve arbitrary discrete relationships rather than smooth, continuous functions. Regardless of the individual stresses and strains, the fuselage of an airplane or the hull of a submarine is a smooth curve; a large hump in the curve indicates an error. Business "curves" or processes are rarely smooth, and a "hump" or exception might well be the more important information. The arbitrary is the rule in business: just consider the irregular number of days in a month, the levels at which income tax rates jump, regular, overtime, and holiday wage rates, the application of local wage taxes by home residence, and the differences in the method of computation of extended term insur-

ance depending on the state in which the insured resides.

This arbitrary nature of business data at first seemed to pose a barrier to the application of automatic-coding techniques. However, the introduction of the generator concept surmounted the difficulty. In the same way that a library of static subroutines, such as sine x and logarithm x is compiled for mathematical problems, a library of generators is set up for data processing. For example, one of a family of tape-handling generators might produce routines to handle "two inputs, both multi-reel with servo swap; three outputs, two multi-reel with servo swap, one single reel; specifications to be supplied defining item size, location of tape label, end of reel and end of file sentinels, and location of block count". The pseudo-code need only specify the names of the inputs and outputs. A translator can select the required generator from the library after consulting the file-designs to determine their input and output specifications, and can arrange these specifications for submission to the generator. These techniques promise to produce coding faster and more accurately than manual techniques.

Having been coded, the various runs must be applied to both sample or generated input data, and to real input data. It is usually necessary to code "one-shot" runs in addition to the processing runs, to create and check the basic files. The coder should be well-acquainted with all system and service routines available to him. In this class fall such routines as "Tape-Comparator", "Corrector", "Sequence Check", and "Analyzer" which, respectively, compare two tapes and report discrepancies, correct tapes, check a tape for item sequence, and analyze the coding of a run and report all cross references.

Debugging

Debugging must be planned when the programming is started. Test data must be made available, and the runs themselves planned with debugging and rerunning in mind. This does not hamper the efficiency of the runs, and may save a great deal of computer and coder time. It is important that the coder plan for debugging. The use of relative coding, proper placing of breakpoints, careful preparation of test data and operating instructions, and good desk-checking all will reduce computer debugging time. Familiarity with routines such as "Analyzer" and "Codedit" and their proper application is advisable. Every effort should be made to insure the correctness of a run *before* it is put on the computer.

After the runs have been individually checked, they must be run as a complete system—first on test data and then on real data. Entry of the real data into the system brings out

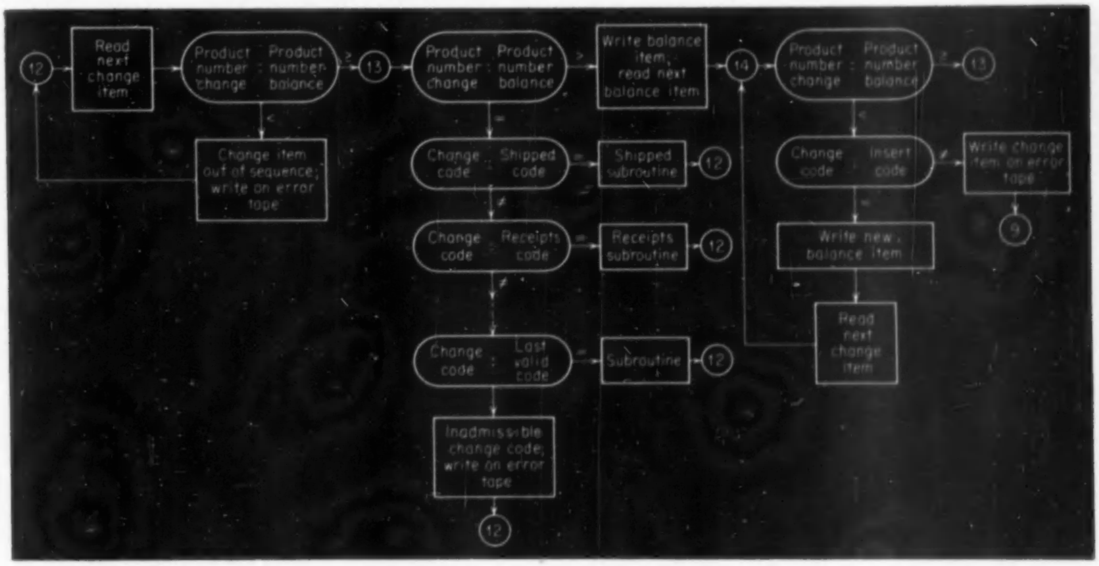


FIG. 5. First flow chart showing logic of data handling. Subcharts are referred to for processing subroutines.

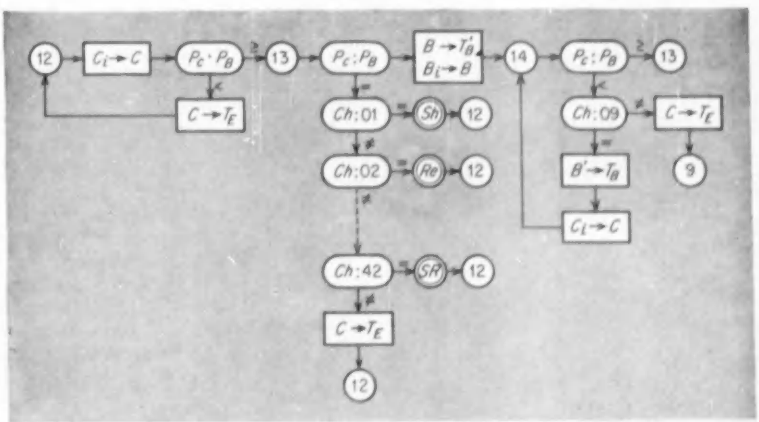


FIG. 6. Outgrowth of Figure 5 as symbols are assigned and programming is subdivided.

the unanticipated requiring correction in programming and coding.

As the data-processing problem passes through the several stages of development there is feedback to the previous steps as shown in Figure 1. No matter how carefully the present procedure or the problem solution are documented, questions will arise at all stages of preparation, and a good communication system is essential.

Running

No sooner has anyone—analyst, methods man, systems specialist, programmer, or coder—run a completed problem than he knows exactly how it *should* have been done. He sees how to save milliseconds, which mount to hours by repetition. He discovers more efficient ways of allocating runs, or even a better way of arranging the system. At present, complete reprogramming is usually too costly; only small changes can be made. It is hoped that automatic coding will help this situation. If the program is prepared in sections and pieced together by the computer at computer speeds, a new piece can be inserted or an old one replaced, also at computer speed.

It has frequently been stated that business problems are static; that they will run the same way for a period of years. It is true that in determining pay, gross pay is computed first, then net pay. But little else remains constant: federal and state laws, union contracts, city ordinances, company decisions, and employee preference cause constant changes, not only in some easily inserted quantity, but also in the way an entire computation is carried out. A change in social security only involves two numbers, the upper limit of income to which withholding applies and the rate of withholding; but a new insurance plan might involve a whole new subroutine.

It should be clear that before a computer can perform control and decision-making functions, it must have available the correct information and the processes for maintaining the correct information. This implies that the preparation of a data-processing problem proceeds by approximation, constantly reviewing what has been done and adding new operations. Thus, a business problem is never completed in the sense that a scientific problem can be completed. It will remain open-ended: standardization, documentation, and communication between analysts, programmers, and coders assume an importance not felt in engineering applications.

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GRACE MURRAY HOPPER

"On my desk," writes Dr. Hopper in telling about herself, "are a rocket trajectory, a turbine problem, information on new storage devices, manuals for completed computers, specifications for projected computers, a logistics problem, plans for a weekend visit to a naval activity, plans for training, and another memorandum on personnel requirements (manpower shortage)."

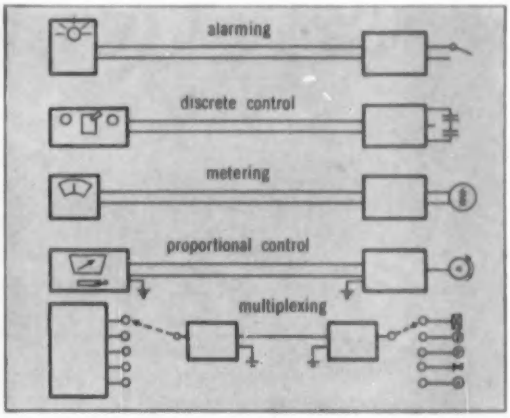
This work, she says, comes under the heading of "Part II" of her life, which began in 1943, when she entered the field of electronic digital computers. Reminiscing about this period, she says, "To share in this development, to watch computers appear in all fields from mines, torpedoes, and missiles to public utility billing has been to watch a whole new industry grow."

But Dr. Hopper has done far more than just watch. As senior programmer in the Eckert-Mauchly Div. of Remington Rand (1950-52) and as systems engineer and director of the company's programming research, a position she holds today, she has trained computer crews, written more than half a dozen books and manuals on computers, and flown all over the country as a computer missionary.

Since the foundation of her education was mathematics, it was inevitable that she move right into this field after receiving her master's from Yale in 1930. It followed a BA from Vassar in 1928 and preceded a PhD from Yale in 1934. From 1931 to 1944 (with the summer of 1943 spent teaching the subject at Barnard), she taught math at Vassar. In 1944 she joined the Navy ("a natural result of my family tradition") as mathematical officer in the Bureau of Ordnance's Computation Project at Harvard and in 1946 became a research fellow in the Engineering Sciences & Applied Physics Computation Laboratory there. Then in 1949 she went to the then Eckert-Mauchly Computer Corp. of Philadelphia as senior mathematician, joining Remington Rand the following year. And during 1952, just when her status at Rand jumped a few notches, she managed to fit in a lecture series in mathematics at Temple University.

how to simplify

REMOTE CONTROL SOLUTIONS



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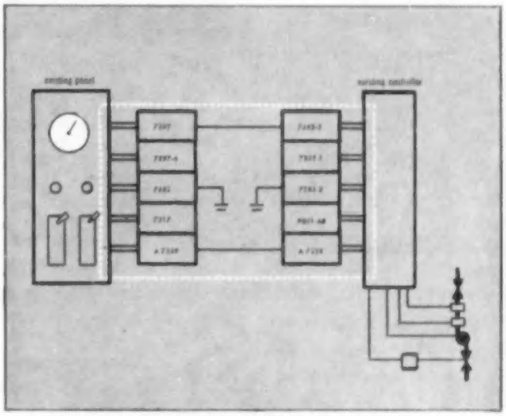

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'Scope "Visualizes" Computer Results

It is difficult to "see" what goes on in a simulated physical system from the abstract presentation of a multi-channel recorder. The system described here paints a dynamic picture of the mechanics on an oscilloscope. This helps the engineer find the optimum simulator settings more quickly, and provides a graphic demonstration of the results of his work for others.

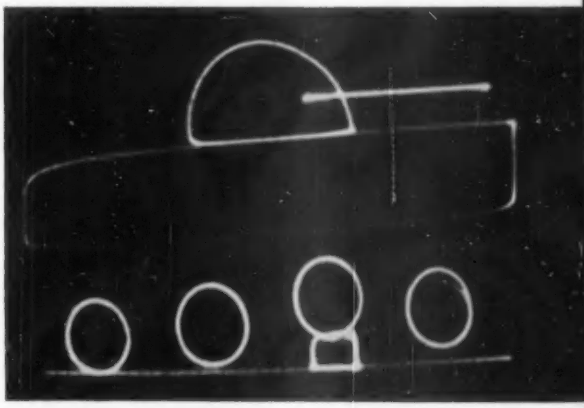

FIG. 1. Dynamic oscilloscope presentation of a simulated tank going over a square obstacle.

I. J. SATTINGER, University of Michigan

Usually, analog computer results are chart recordings of the variables of interest drawn by multi-channel graphic recorders. The accuracy of the results is high, but understanding them is slowed by the need to visualize physical motion in time from curves drawn in space.

The display system described here, developed at the University of Michigan for the Detroit Arsenal, permits the dynamic response of a simulated system to be displayed pictorially on a cathode-ray oscilloscope. It is a valuable supplement to graphic recordings, because it displays physical action directly, thus eliminating the visualization step that can be very difficult and time-consuming for complex systems.

The kinds of pictorial displays possible with this system are indicated by Figures 1 and 2. The display system itself, Figure 3, is a general-purpose device. When the proper interconnections are made at a patchboard, as many as 12 figures of several different shapes (such as squares, circles, lines, or semi-circles) can be presented at one time. The size and position of each figure can be controlled by potentiometer adjustment or by computer voltages added to the position voltages. Computer voltages can move each figure horizontally and vertically and can rotate it through a small angle.

System description

To produce a figure and control its position on the oscilloscope, one set of three voltages must be summed in an operational amplifier and fed to the X input, and a second set of three voltages summed and fed to the Y input. Each set of voltages consists of

(1) an 1,800-cps voltage for producing the characteristic shape of the figure

(2) a fixed dc voltage for locating its steady-state position

(3) a slowly-varying dc voltage supplied by the computer to move the figure about its steady-state position.

To provide for the simultaneous presentation of 12 figures, a motor-driven, two-pole commutating switch connects in sequence each of the two summing amplifiers to 12 resistor summing networks at a rate of 30 complete cycles per second.

The system can generate 14 pairs of voltage waveforms, each pair representing a figure. Of these 14, any 12 may be shown simultaneously. The figures available include eight circles, five squares, and one semicircle. Also, the appearance of these basic configurations may be altered; e.g., the circles may become ellipses, the squares may become rectangles or lines, and the semicircle may become a quarter-circle.

A circle may be formed as shown in Figure 4. If a sine wave is applied to the X input of the oscilloscope, and a sine wave of the same frequency and amplitude, but shifted 90 deg in phase, is applied simultaneously to the Y input, the resultant trace is a circle (assuming equal deflection sensitivities for the X and Y axes of the oscilloscope). The circle is made an ellipse by making the amplitudes of the voltages different. If the sine wave voltages applied to the X and the Y inputs are clipped, a square is formed. A rectangle is produced by decreasing the amplitude of the waveform applied to either the X or Y input. A semicircle results when a sine wave is applied to one input and a half-wave rectified voltage to the other. A quar-

ter-circle results from using half-wave rectified voltages for both inputs. These circuits use conventional RC phase shifting networks and germanium diodes.

A patchboard is used for manually connecting each set of voltages to a summing resistor network. Three or four resistors are tied to each contact of the commutating switch, so that a positioning voltage, a computer voltage, and one or two figure-generation voltages are summed in the amplifier.

The commutating switch is a low-noise, double-pole type made by Applied Science Corp. of Princeton for telemetering service. Each pole of the switch has 60 break-before-make contacts to which connection is made by a wiper arm. The two arms are driven through a 5:1 gear train by a synchronous motor, whose 1,800-rpm speed produces a wiper-arm speed of 6 rps. Of the 60 contacts, every twelfth contact is connected together so that five frames of 12 elements each are painted for every revolution of the wiper arm. This results in a total of 30 frames per second. Each pair of contacts is maintained long enough for an element to be traced about three times.

A blanking pulse blanks out the trace during the interval of switching from one set of contacts to the next to eliminate trace lines between the various elements that would otherwise obscure the picture. The leading edge of the desired blanking pulse is obtained from a magnetic pickup near a wheel mounted directly on the shaft of the switch driving motor. Each time one of 12 magnetic inserts in the wheel passes the magnetic pickup, a voltage pip is generated. This voltage pip triggers a monostable multivibrator, which produces a square voltage pulse of the proper amplitude and duration for blanking. This voltage is applied to the Z input of the oscilloscope.

Two feedback summing amplifiers are used, one for X and one for Y. Each individual set of summing resistors on the patchboard serves in turn as the input network to a summing amplifier.

Two servomultipliers are provided for special effects, e.g., making the size of a figure correspond to a computer output voltage. For this purpose, the computer voltage is fed to the servo input. The X and Y figure generation voltages are applied to two multiplier potentiometers. The voltages available at the arms of the potentiometers are then voltages with the original waveform but with amplitudes proportional to the computer voltages.

A servomultiplier can also be used

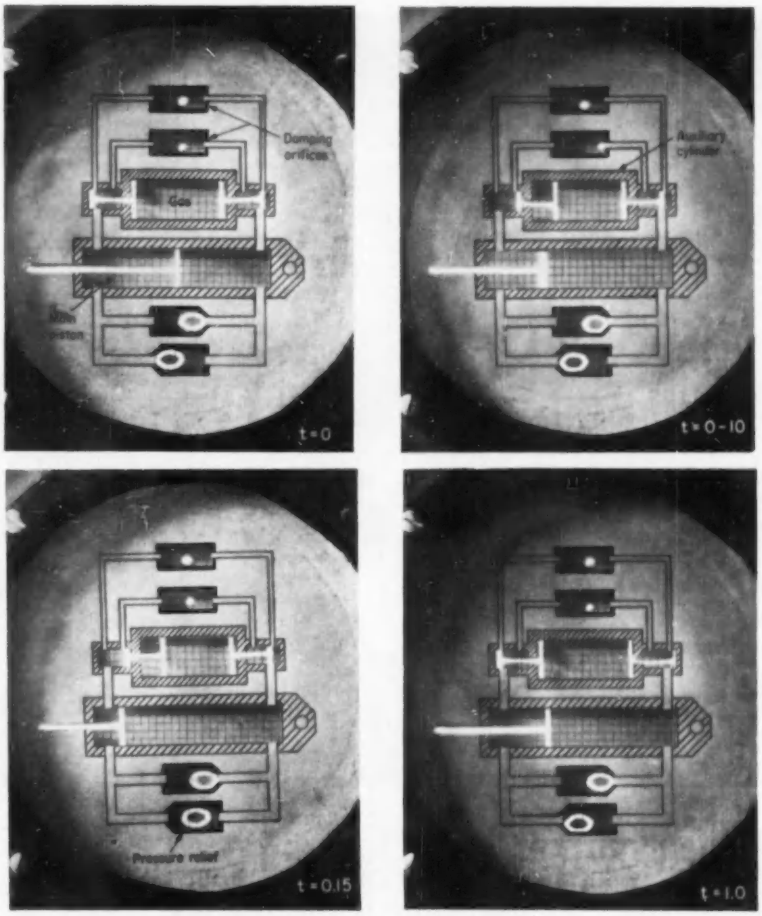

FIG. 2. Mask for nonmoving parts makes presentation simpler. Above sequence for gun-positioning hydraulic cylinder starts when tank hits severe bump at t = 0. At t = 0.10, main piston displaced by gun inertia compresses gas spring in auxiliary cylinder; at t = 0.15 it opens pressure relief valve because auxiliary cylinder is fully displaced; at t = 1.00 it has returned to rest with a permanent displacement because some oil has transferred from left to right around the main piston.

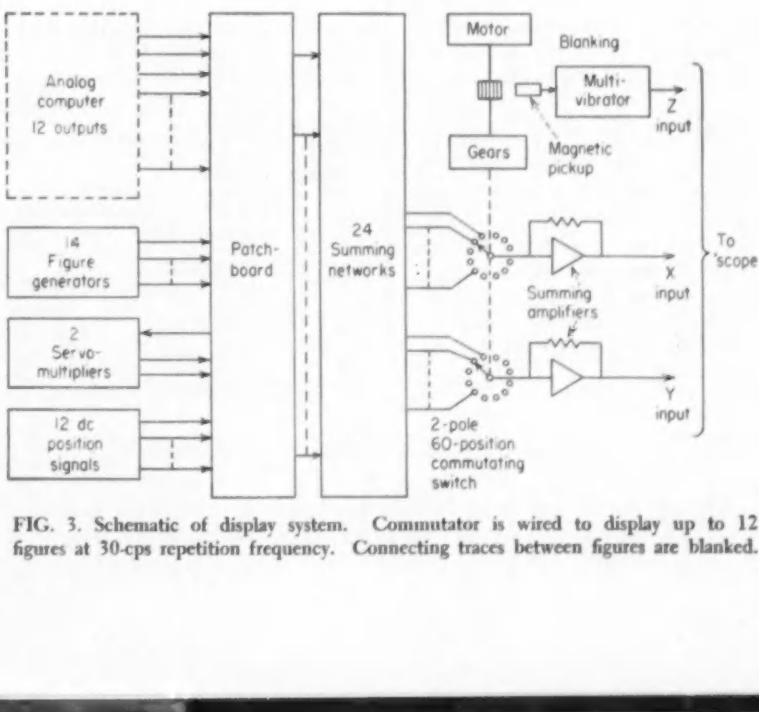

FIG. 3. Schematic of display system. Commutator is wired to display up to 12 figures at 30-cps repetition frequency. Connecting traces between figures are blanked.

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CIRCUIT	Three Phase Bridge Rectifier, Resistive Load.
D-C OUTPUT	280 volts, 215 amperes, 60 kilowatts.
RECTIFIER LOSSES	Less than one percent (½ KW).
COOLING REQUIRED	One 6½ inch square ⅛" thick copper fin for each of six rectifying units when used with 2000 fpm 30°C forced air. Free convection cooling may be utilized by increasing the fin area.
VOLUME	Total volume of rectifiers and fins—less than ⅓ of a cubic foot.

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to produce pitching of the hull of the tank shown in Figure 1. A rectangle is used to represent the hull. To make the rectangle pitch, a portion of the X rectangle voltage proportional to the pitch angle is added to the Y rectangle voltage. This component is obtained from the arm of the potentiometer of a servomultiplier. The input to the servomultiplier is the computer voltage representing pitch, and the voltage applied to the potentiometer is the X rectangle voltage.

Although any size oscilloscope can be used for display purposes, a 17-in. or 21-in. screen provides the most accurate and effective picture. The oscilloscope must, however, have provision for blanking. In some cases, an overlay applied to the face of the oscilloscope can be used to show the fixed parts of the simulated mechanism. This can improve the presentation by allowing a more detailed view of the mechanism and by making it unnecessary to use display channels for non-moving parts (see Figure 2).

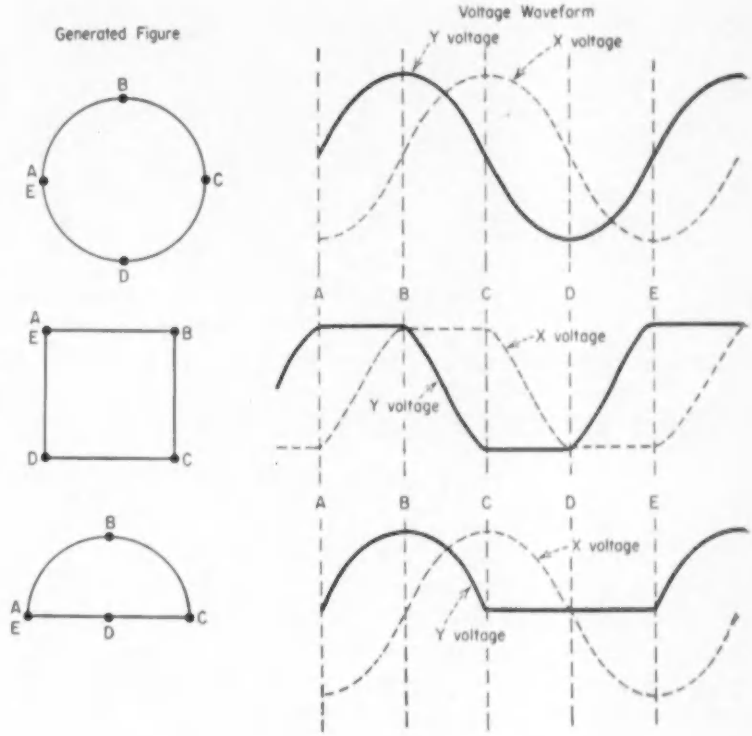


Fig. 4. Figure generator output signals.

An Analog for Process Lags

Using conventional analog techniques, lots of expensive computing equipment can be tied up merely to simulate a transport lag, which is only a single characteristic of a possibly very complex process. And if the transport lag is variable, it can't be done with conventional circuits. Here's a circuit that simulates variable time delay with a minimum of equipment.

C. H. SINGLE
Berkeley Div.
Beckman Instruments, Inc.

Many processes contain time lags due to transport velocities between measurement points. Such lags approximate pure time delays—little waveform distortion is introduced by frequency-sensitive elements and they can be very long compared to distortion-producing inertia lags. Transport lags of many minutes are not unusual. Furthermore, there are processes in which the time delay varies because the transport velocity varies during operation.

Any analog study of a process that contains transport lags requires an adequate simulation of pure time delay. Good simulation of time delays in the order of minutes can mean tying up possibly dozens of computer amplifiers for the time delay alone if conventional analog techniques are used. And the conventional circuit becomes impractical if the delay time must vary with time.

Pure time delay

The output of a system with pure time delay, τ, is related to the input by

$$E_o(t) = E_i(t - \tau)$$

The Laplace transform is

$$\frac{E_o}{E_i}(s) = \epsilon^{-\tau s} = \epsilon^{-j\omega\tau} = 1\angle -\omega\tau$$

which is pure phase shift, without attenuation. Pure phase shift is a characteristic of a theoretical, loss-free transmission line.

Thus, there are two basic approaches to the simulation of time delay:

- the synthetic approach, which attempts to construct an adequate loss-free delay line. Because sections of the "delay line" must be lumped to conserve expensive computing elements, delay time cannot be varied continuously. When changing delay time, the signals stored in successive sections are distorted. This does not happen when the transport velocity changes in the real process. Low distortion is costly by this method.
- the analytic approach, which develops a computer model of a mathematical approximation for $\epsilon^{-\tau s}$. This is the technique used to develop the

time delay circuit described here.

An approximation for $\epsilon^{-\tau s}$ that converges rapidly is:

$$-\frac{E_o}{E_i}(s) = \prod_{i=1}^{i=n}\left(\frac{\tau_i^2 s^2 - 2\zeta_i \tau_i s + 1}{\tau_i^2 s^2 + 2\zeta_i \tau_i s + 1}\right) \leqq \epsilon^{-\tau s}$$

$$\text{where } \tau = 4\sum_{i=1}^{i=n}\zeta_i \tau_i$$

which is a product of quadratic terms. As it turns out, the phase shift limit and step function response are inadequate for $n=1$. The basic delay element recommended is an $n=2$ approximation with a modified transfer function:

$$-\frac{E_o}{E_i}(s) = \frac{(\tau_1^2 s^2 - 2\zeta_1\tau_1 s + 1)(\tau_2^2 s^2 - 2\zeta_2\tau_2 s + 1)}{(\tau_0 s + 1)(\tau_1^2 s^2 + 2\zeta_1\tau_1 s + 1)(\tau_2^2 s^2 + 2\zeta_2\tau_2 s + 1)}$$

Figure 1 shows the computer diagram for this approximation. The damping coefficients and time constant ratios recommended give the best approximation to pure time delay for this expression. The phase shift limit of valid approximation for this circuit is 7.44 radians. Thus, the frequency limit is

$$f = \frac{7.44}{2\pi\tau} = \frac{1.18}{\tau} \text{ cps}$$

Continuous time delay variation is possible by varying the ganged combination of resistors R and capacitor C_o. A suggested range is from zero to 11 sec, which gives sufficient flexibility for most applications. Longer delay times can be produced by cascading two or more such circuits.

The circuit of Figure 1 permits continuous variation of delay time, but not without distortion during variation. (A modified circuit with an additional operational amplifier allows simultaneous variation of delay time and input signal without distortion.

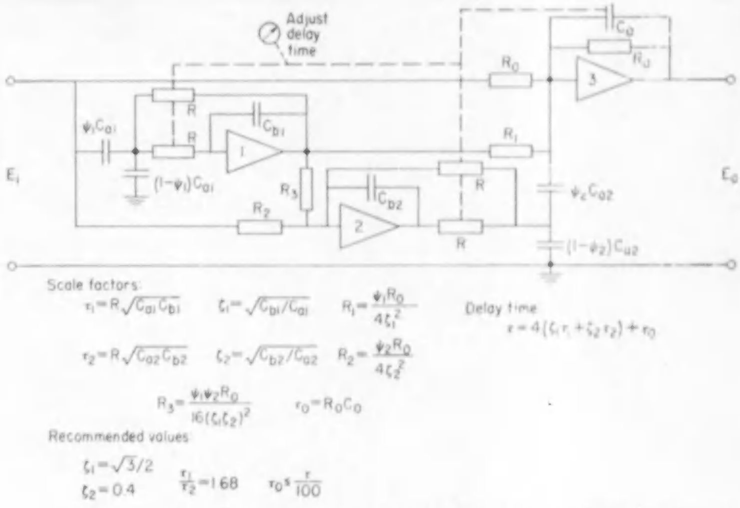


FIG. 1. A computer circuit for time delay based on a quadratic approximation of $\epsilon^{-\tau s}$. Varying ganged elements varies delay time.

Figure 1 is adequate for most applications.)

Step function response

Figure 2 is the theoretical step function response for the circuit of Figure 1, compared to an ideal time delay. Note that the amplitudes of the peaks marked 1, 2, and 3 are controlled by R_2, R_3, and R_1. The values shown are theoretically optimum, and the adjustment procedure is indicated because the controls are interacting. This adjustment need only be made once if components are stable.

Figure 3 shows the response to a step input for three of the circuits of Figure 1 in cascade. Each circuit was optimally adjusted as in Figure 2. The result of Figure 3 was obtained experimentally because of the difficulty of calculation. Note that for three cascaded time delays

$$f = 3 \times \frac{1.18}{\tau} = \frac{3.54}{\tau} \text{ cps}$$

$$\phi_{max} = 1{,}270 \text{ deg}$$

In other words, for a given frequency the phase shift limit is increased three times, or, for a given time delay the frequency limit is increased three times.

The limitation of this circuit is essentially one of noise output at delay times below 1 sec. In a high-quality analog computer, where the noise level of the amplifier and patchboard system is 2 mv rms referred to the amplifier grid, the noise output of the circuit of Figure 1 is:

$$E_{noise} = \frac{0.040}{\tau + 0.040} \text{ rms volts}$$
(essentially 60 cps)

Thus, for 1-sec delay time the noise is 40 mv rms; for 2 sec, 20 mv, etc.

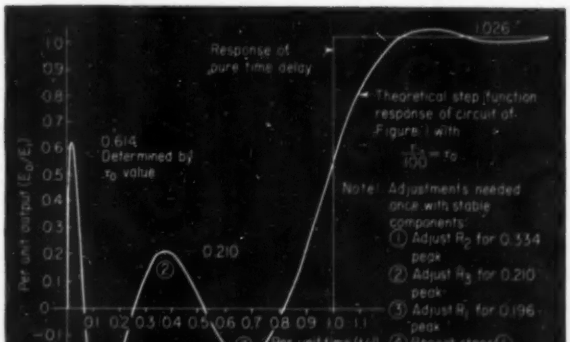


FIG. 2. Theoretical step function response of circuit of Figure 1.

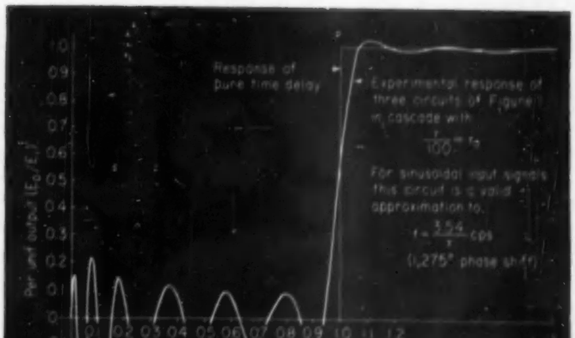
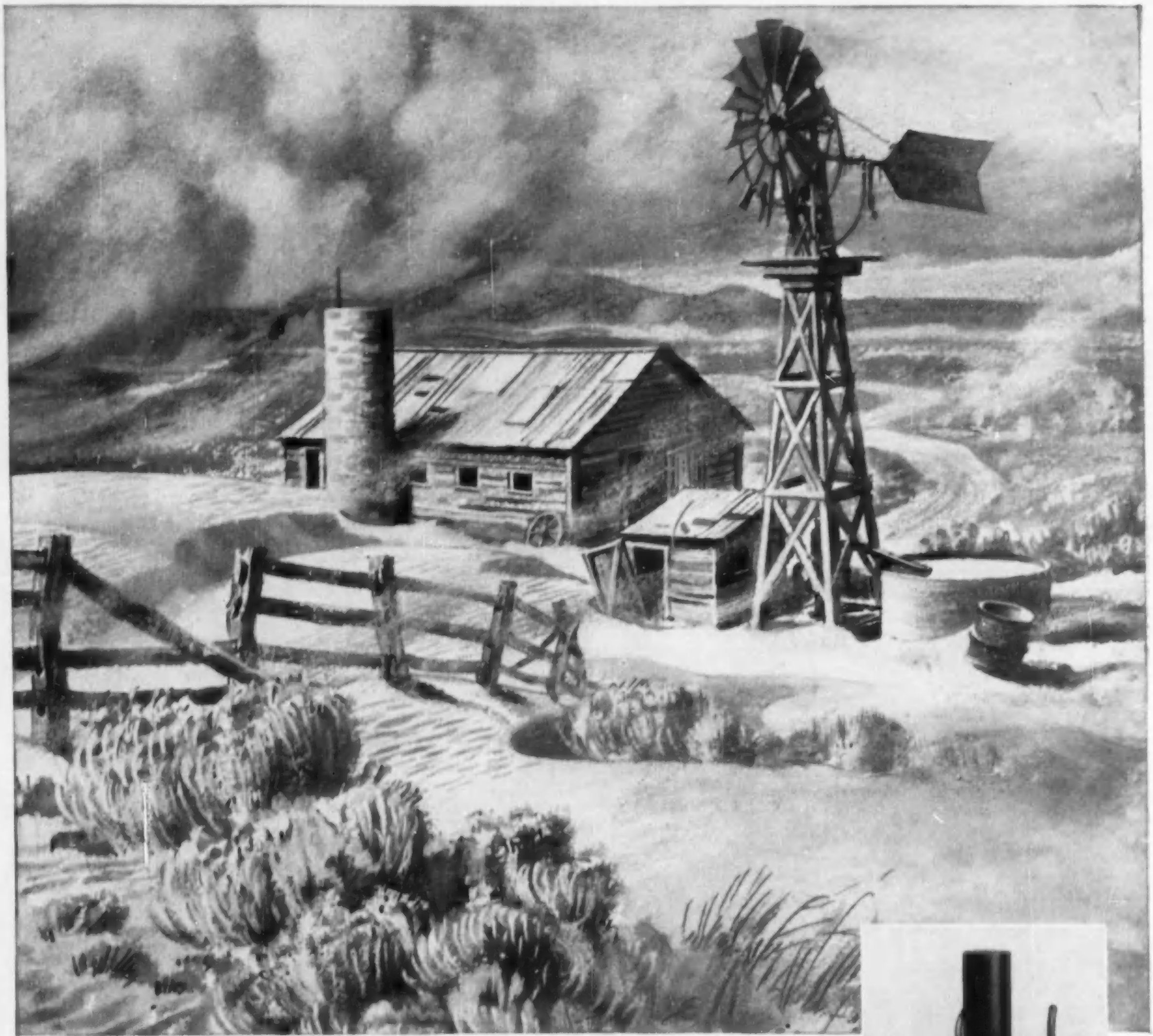


FIG. 3. Experimental step response of three circuits of Figure 1 in cascade.



Generate Ramps and Exponentials Electromechanically

P. C. WHARFF
The Dow Chemical Co.
Pittsburg, Calif.

Very slow-changing functions, like those useful for large-process analysis, are probably generated easiest by mechanical means. This particular generator is versatile.

The Research Instrument Design Group at Dow Chemical has designed and developed a flexible electromechanical variable function generator that can generate:

- ▶ variable-rate linear sweeps
- ▶ variable-exponent exponential sweeps
- ▶ variable-parameter parabolic sweeps

The instrument is intended for use with an X-Y recorder or in laboratory experiments where such voltage sweeps may be used.

A reversible synchronous motor drives the ball-disc integrator through a magnetic clutch. The integrator cylinder, in turn, drives a ten-turn potentiometer through gears and a slip clutch. The sweep rate of the output voltage is proportional to the speed of the disc and the displacement of the ball carriage from the center of the disc. Displacement of the carriage is controlled in three ways:

1. By manual setting of the set knob, which positions the ball carriage via miter gears and a rack and pinion. This knob can be locked in position to select any speed within the range of the disc. The potentiometer output then increases linearly with time.
2. By leaving the set knob unlocked, which causes the integrator output to drive the ball-carriage via the slip clutch. Thus, the ball-carriage position, which determines the output speed, changes in proportion to the output speed. The potentiometer output varies exponentially.
3. By leaving the set knob unlocked and driving the ball-carriage via the input coupling. Other functions can be generated in this way. If the input coupling is driven at a constant rate, as from the drive motor, the electrical output varies parabolically.

The basic sweep rate depends on the motor speed. For the kind of motor used, a range of 300 to 1 is available in the same frame. The input speed can also be varied by the change gears. Gear ratios between the integrator and the rack and pinion can be changed to vary the exponent for the exponential sweep.

The unit is completely contained in a 7-by-7-by-10-in. cabinet, Figure 2, and has provision for external triggering of the sweep.

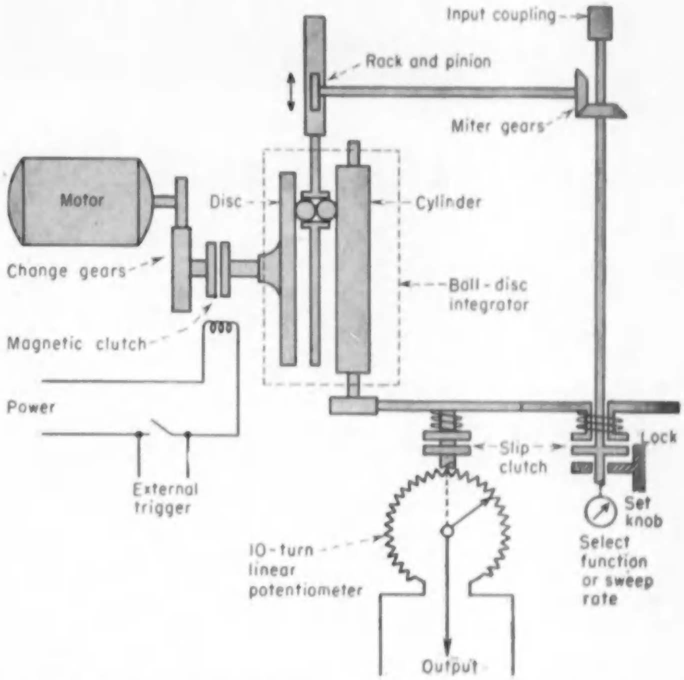


FIG. 1. Function generator produces a voltage output as a function of time.

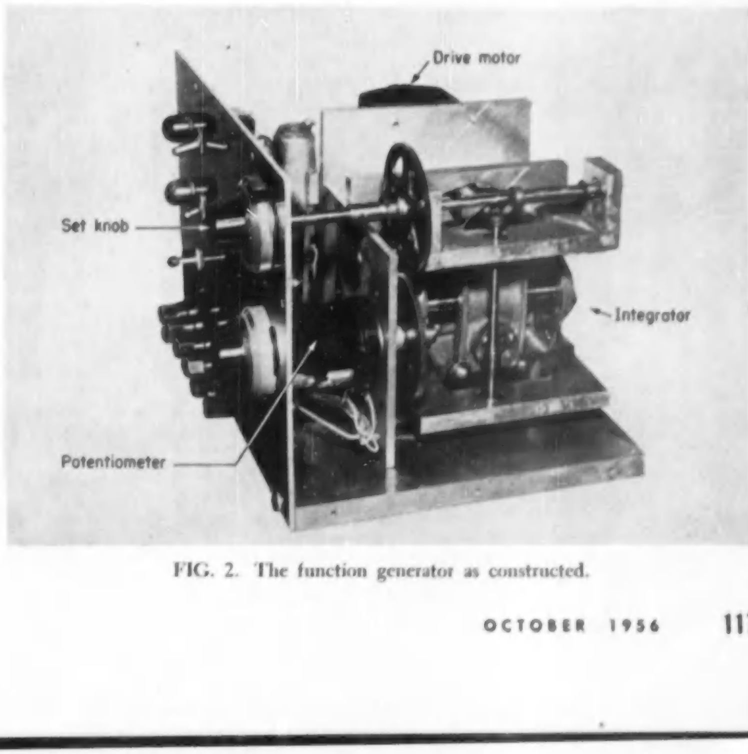


FIG. 2. The function generator as constructed.

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Now...all 3 in one 'American' Thermometer

Only this new American Thermometer* gives you the three features most demanded in a dial thermometer. The "Every Angle" design allows you to install this thermometer *anywhere* . . . then angle it in the direction that provides easiest reading. The anti-parallax Maxivision dial guarantees the surest, sharpest, easiest reading. Graduations are carried on a raised ring, set close to the cover glass, with an index-type, functional pointer set at the same level. The result – no perspective effect – parallax error practically eliminated. Finally, bi-metal actuation insures high sensitivity, economy, and surety of operation.

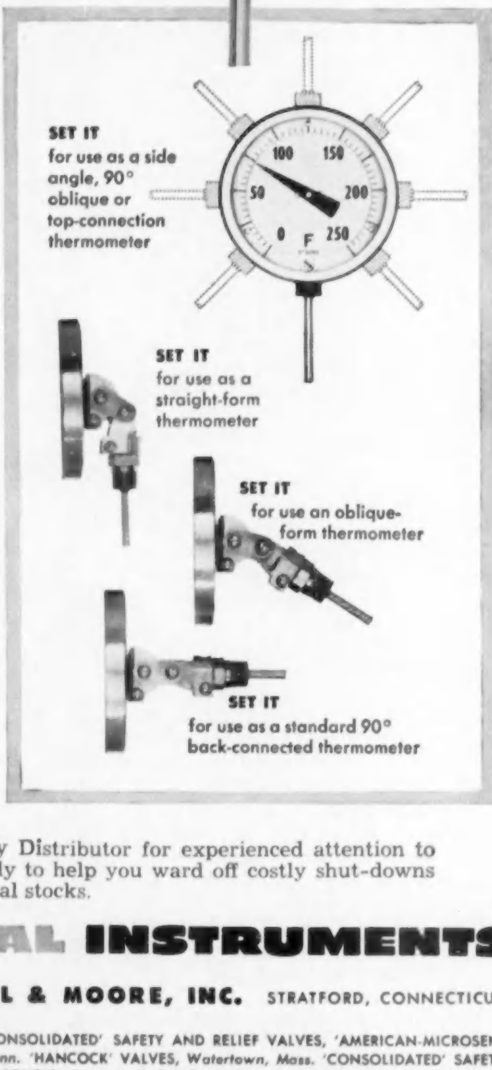
Install the new American "Every Angle" Bi-Metal Dial Thermometer anywhere – inside or out. Its climate-proof case defies any weather condition. The full use of these thermometers in any process plant makes possible temperature readings with the same ease and facility of those of a pressure gauge. Write today for complete information. Ask for Bulletin 148.

*Pat. App. For

SPECIFICATIONS

5-Inch Type 5-6060 American "Every Angle" Bi-Metal Dial Thermometer

Temperature Ranges: From minus 80° to plus 1000° F. Accuracy within 1% of range. *Dial Size:* 5". Scale approximately 10½" long. *Bi-Metal Coil:* Low mass, with single helix close to inside wall of stem assures high sensitivity. Silicone fluid dampens vibration, accelerates transfer, speeds response. *Case:* Stainless steel. *Bezel:* Threaded to case. *Front:* Clear, extra-heavy glass set in channeled gasket to seal case. *Pointer:* Functional type, adjustable from front. *Stem:* Lengths – 4" to 24", 18-8 stainless steel. All joints welded. *Connection:* Fixed, ½" NPT. *Separable Sockets:* Available in all materials and sizes normally required.



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An Integrating Meter for Very Large Flows

Field recorders for water-supply flow measurements in isolated locations should be simple, and should not depend upon power supplies that can fail or that need winding. This one records flow in acre-feet over long periods and draws its power from the water itself.

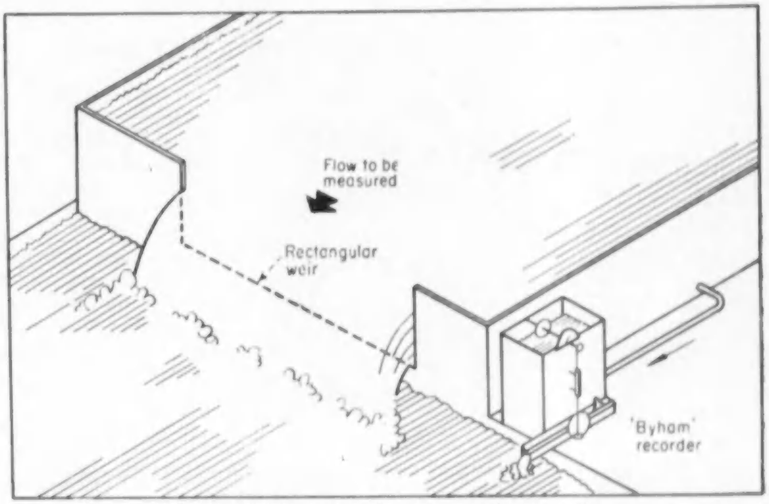


FIG. 1. Field setup for the automatic flow recorder.

H. F. Byham of the State River & Water Supply Commission of Victoria, Australia, has designed a new field meter for automatically recording large flows of water over long periods. The new recorder draws its power from the head of water on the weir, and has no clock mechanisms. These mechanisms have inherent disadvantages in field use: power supply may fail, rewinding may be difficult in isolated locations, and specialist attention is needed for repairs.

The recorder operates in conjunction with a fixed-crest rectangular weir. A small fraction of the flow over the weir is diverted, as in Figure 1, to fill a float chamber to the level of the weir pool. The chamber is filled through a pipe below the level of the weir crest and is large enough so that the loss of head due to the small flow is negligible, see Figure 2.

The chamber discharges into an inclined trough through an orifice at a rate proportional to the square root of the head on the weir. A small Dethridge wheel in the trough drives a disc at this same rate. The flow over a rectangular weir is proportional to the head times the square root of the head. A friction wheel is positioned on the vertical centerline of the disc so that it is at the center of the disc when the water in the chamber is at the weir crest level. The friction wheel is moved by the float a distance proportional to the head on the weir. Thus, the friction wheel rotates at a rate proportional to the head times the square root of the head, or to the flow rate over the weir.

The friction wheel drives a mechanical counter that records the total flow over the weir in convenient units, such as acre-feet. The counter is mounted on the friction wheel shaft, and moves up and down with the friction wheel. Its body is kept from rotating by vertical guides in which it slides.

A pointer added to the float pulley indicates on an appropriate dial scale the instantaneous rate of flow over the weir.

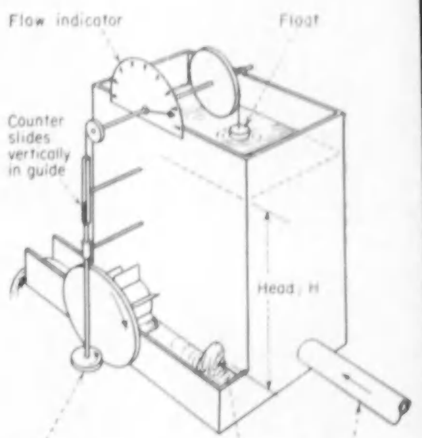
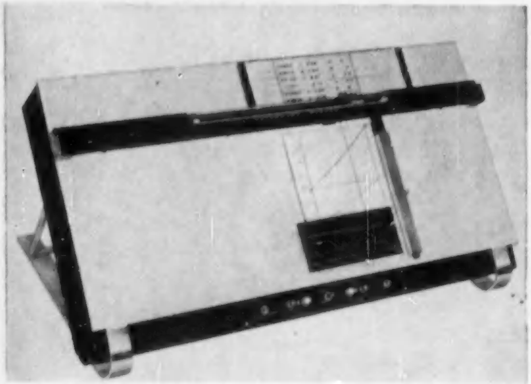


FIG. 2. Flow through the orifice and the head of water on the weir control the rate of the counter spindle.

NEW PRODUCTS

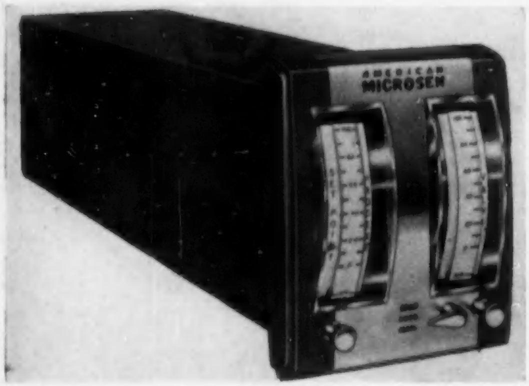
LISTING IN GROUPS



EQUATION FINDER cuts engineering time.

This electrically-driven analog computer, the Equameter, performs harmonic analysis and curve fitting on plotted or recorded curves. Good results are quickly obtained at low cost by relatively inexperienced operators. The instrument will analyze a curve in terms of a Fourier series, a power series, or a least-squares fit, and will produce a slope or integral equation of the curve. The resulting equations are recorded on a program sheet specially designed for each type of analysis. Typical applications are analysis of frequency components of complex harmonic wave forms in rotating helicopter blades, vibrating beams, oscillating systems, electronic circuits, and distortion in amplifiers.—The Gerber Scientific Instrument Co., Hartford, Conn.

Circle No. 1 on reply card

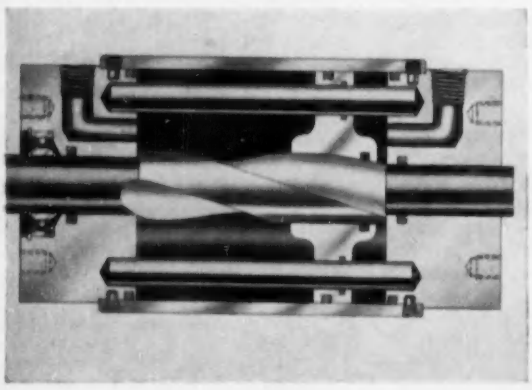


ELECTRONIC CONTROLLER uses transistors.

Shown is a new electronic process controller designed to incorporate the functions of data indication and control in a single, panel-mounted case. Transistors and printed circuity save space and improve reliability and service life.

A recording controller is available with the same features, also incorporating a 3-inch strip or card chart recording mechanism. The recording controller occupies a panel space 5¾ in. high by 6½ in. wide. The functions of indicating or recording, controlling, and manual-automatic operation are accomplished by separate chassis within the instrument case. These units are plugged into terminal connectors, so each can be replaced without disturbing the functioning of the others. —Manning, Maxwell & Moore, Inc., Stratford, Conn.

Circle No. 2 on reply card



ROTARY ACTUATOR features new construction.

This line of self-contained rotary actuators, which will operate on air, gas, water, or oil pressure, delivers fast, positive rotary motion with a piston and simple internal helix. The actuators can be stopped at any point in the rotation cycle and held indefinitely. They have no by-pass leakage or pressure loss, and, because of the internal helix, the work load is held firmly in position and cannot back off under reverse tension, shock, or vibration, even in case of a complete power loss. Applications include indexing, positioning, transferring, etc. Standard diameter sizes include 3, 4, 5, 6, and 8 in. Standard rotation cycles are 0 to 100, 190, 280 and 370 deg.—Carter Controls, Inc., Lansing, Ill.

Circle No. 3 on reply card

POT CONTROLLERS have anticipatory action.

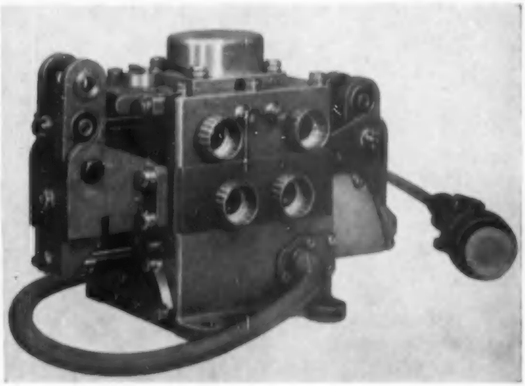
Two new non-indicating potentiometer-type controllers are available for applications in batch process work. One model is a simple on-off controller for applications where transfer lag and dead time can be reduced to a negligible value. The second model is an anticipatory time-proportioning controller which compensates for system inertia. A time-constant network within this controller causes a control device to go to the "off" position slightly before the normal "off" point is reached; likewise, the "on" cycle starts slightly ahead of the normal controller "on" point. This anticipatory action starts as soon as the controlled temperature comes within the proportioning hand of the instrument.—Barber-Colman Co., Rockford, Ill.

Circle No. 4 on reply card

SERVO VALVE coordinates control functions.

A dual-input servo valve combines artificial flight stability augmentation and the work of autopilots with pilot boost servos to give electro-mechanical aircraft surface-position control. Pilot-boost servos are often necessary because high control surface loads render direct control impracticable. As operational requirements increase, artificial flight stability augmentation through the servos becomes necessary. Autopilots also work through the servos. The valve coordinates these functions, permitting direct mechanical-hydraulic flight control, combined mechanical-hydraulic and electrohydraulic control, and increased low-amplitude resolution and frequency response.—Moog Valve Co., East Aurora, N. Y.

Circle No. 5 on reply card



PANEL FREQUENCY METERS to 10,000 cps.

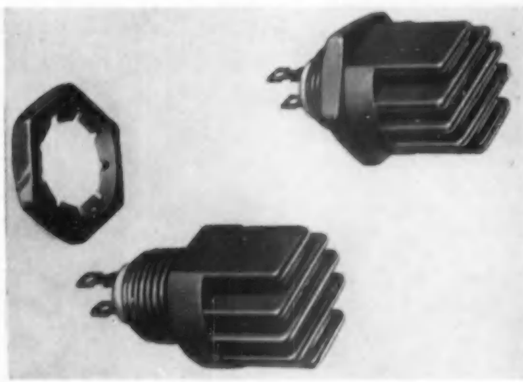
A radically different operating principle in this low-cost frequency meter makes possible precision indication of line frequencies up to 10,000 cps. The meter has a galvanometer movement with a frequency sensitive network containing two double "T" bridges. One of the bridges is at balance below the lowest frequency reading of the instrument; the other at balance above the highest frequency reading. The output of each bridge is rectified, and the galvanometer indicates the balance position of the dc bridge formed by the two rectifiers. All harmonics cancel each other out and the indication becomes independent of wave form. Important features are: nominal center frequency is a nil reading, independent of voltage; accuracy within 0.25 percent of center scale readings; current consumption, 2 to 4 ma. Meters have ranges from 40 to 10,000 cps.—Gary Wells Co., New York, N. Y.

Circle No. 6 on reply card

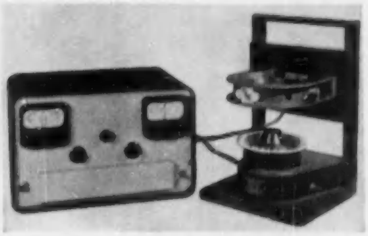
POWER RESISTOR keeps cool in new housing.

High power rating and subminiature size are coupled by a unique housing design in this 25-watt resistor. A black anodized aluminum housing with a new fin design affords both protective covering and high heat dissipation. Units have standard resistance values to 15,000 ohms, and tolerances vary from plus or minus 0.05 percent to plus or minus 5.0 percent. Temperature coefficient of wire is 0.00002 in./deg. C. Voltage breakdown is 1,000 vdc, hi-pot test. Rating is at 25 deg C; maximum operating temperature is 265 deg C. Elements are silicone sealed for protection against moisture, shock, and salt spray. Lug type terminals are provided.—Dale Products, Inc., Columbus, Neb.

Circle No. 7 on reply card



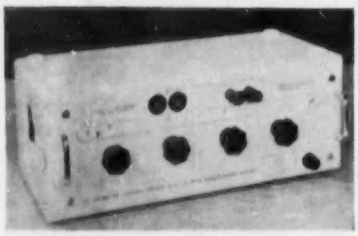
RESEARCH, TEST & DEVELOPMENT



ROTOR BALANCER

The instrument shown here rapidly balances all types of rotors, including those of gyroscopes, high speed grinding heads, motors, and turbines. Equally suited for laboratory and production work, it can identify and measure vibration frequencies other than those arising from unbalance. A computer unit computes the magnitude of the corrections required in any two correction planes selected, and the angular correction position is obtained by comparing the outputs of two electromechanical transducers with a photoelectric reference signal from the spinning rotor. Maximum rotor dimensions are 5 in. in diam, 8 in. long; weights go to 20 lb.—M. Ten Bosch, Inc., Pleasantville, N.Y.

Circle No. 8 on reply card



DECADE CAPACITOR

The three terminals of this new decade standard capacitor permit it to be used as a grounded or ungrounded component. Its total capacitance range extends from 100 mmf to 1.11 mf. Settings are made on three decade scales and one continuously variable air capacitor scale, with the value set at each decade appearing in a window above the adjusting knob. Error is less than 0.2 percent. The unit is well suited for calibration of capacitance bridges and meters, laboratory testing of integrators, computers, and low-level ac amplifiers, and for use as a component in laboratory constructed circuits. —Federal Telephone & Radio Co., Clifton, N.J.

Circle No. 9 on reply card

IMPEDANCE COMPARATOR

A new high-precision impedance comparator indicates differences in both impedance magnitude and phase angle between two components. These differences can be determined to within 0.01 percent and 0.0001 radian, respectively. The instrument can be used for measuring drift of deposited carbon resistors and phase shift in wire wound resistors, comparing samples of dielectric materials, and inspecting balanced transformer windings. Relay-rack or bench mounting is available.—General Radio Co., Cambridge, Mass.

Circle No. 10 on reply card

DIGITAL METER

High accuracy, excellent resolution, and low cost are features claimed by this new digital volt-ohmmeter. Designed especially for industrial uses, its in-line luminous numerical readout can be read from a distance of 30 ft or more. Measuring dc volts, the reading is within 0.1 percent of the correct value. On ac volts, it is accurate to within 2 percent of the full scale from 30 cps to 3 mc. Ranges are as follows: 0.01 to 999 vac; 0.001 to 999 vdc; and 1 ohm to 9.99 megohms. The meter is available in portable and rack mounted models.—Non-Linear Systems, Inc., Del Mar, Calif.

Circle No. 11 on reply card

HIGH-VACUUM STILL

A new, high-vacuum, brush-type still of high fractionating power is capable of separating heat sensitive materials with molecular weights up to 900 at pressures as low as 1 micron Hg. The still is designed for batch-type laboratory work in oil, chemical, pharmaceutical, and allied industries. It is adaptable to a wide variety of distillation techniques, having a distilland capacity of 100 to 1,500 cc and a distillation rate of a few drops to 100 cc per minute. Exact regulation of the boiler up to 300 deg C is provided by variable transformers.—Consolidated Electrodynamics Corp., Rochester, N.Y.

Circle No. 12 on reply card

CONDUCTIVITY GAGE

The thermal conductivity cell in this gage incorporates six thermocouples, arranged to compensate for temperature changes in the gas and rate of change of temperature effects. The thermal conductivity elements are made entirely of noble metals, are directly heated with ac, and have a direct millivolt electrical output. The instrument finds applications in chemical analysis of gases and in detection of explosive gases and vapors. When used with gases of high thermal conductivity, such as helium, it can act as a tracer.—Hastings-Raydist, Inc., Hampton, Va.

Circle No. 13 on reply card

SUB-SYSTEMS

PROPORTIONING SYSTEM

Combining a control system with an IBM printing summary punch, an automatic electronic proportioning system records formulas and weighings by means of a recording device interlocked with the action of the proportioning panel. Information is transmitted from the control system

in automation . . .

nothing works if the connector fails!

Wherever you go in an automatic control system you find infinite care taken to provide fast, accurate and trouble-free operation in every element . . . whether it be gears, relays, solenoids, or basic electronic components.

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G. B. SHAW, *Vice President—Procurement*
The Glenn L. Martin Company

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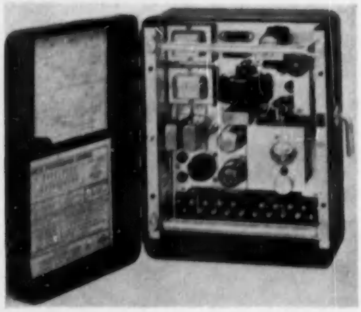


by digitizing equipment, which digitizes individual weighings and sends the information to the summary punch. The equipment processes billings, maintains inventory control, and keeps records of weighing and proportioning.—Richardson Scale Co., Clifton, N. J.

Circle No. 14 on reply card

FLAME CONTROL

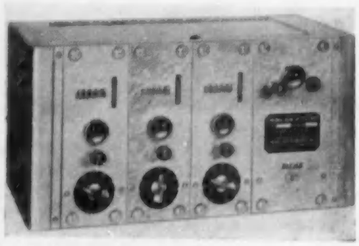
This primary control, which programs and safeguards the entire operating sequence of fully-automatic rotary register oil and gas burners, uses two flame-sensitive scanners. One scanner monitors the pilot flame and supervises the light-off sequence, while the other safeguards the main flame. This arrangement provides additional safety against off-ratio firing. During normal operation, the control provides for prepurge, pilot-proving, limited trial-for-ignition of main fuel, and post-purge periods. If a flame failure occurs during the startup or operating periods, fuel is shut off within 1 sec.—Electronics Corp. of America, Boston, Mass.

Circle No. 15 on reply card

LIQUID FEEDERS

Available in both simplex and duplex models, a series of liquid feeders will handle all types of liquid materials with high accuracy, regardless of changes in viscosity, specific gravity, or temperature. Units are available with maximum feed rates up to 60,000 lb/hr. Feeding mechanisms may be varied to suit the job, and include various types of control valves, gear pumps, and other positive displacement pumps. They can be made to discharge into either pressure or vacuum and can be controlled electronically or pneumatically or placed by pneumatic, electrical, or line shaft mechanisms. Operating on a deadweight principle, the feeders incorporate a memory device which automatically detects and corrects any overfeed or underfeed condition. A broad 100-to-1 feed range permits adjustment to meet changes in formulation requirements or increased production loads.—Omega Machine Co., Providence, R. I.

Circle No. 16 on reply card



VOID DETECTOR

Said to offer distinct advantages in quality control, this new electrical instrument detects holes in any material which is electrically nonconducting. The standard model tests materials such as paper, plastic, and rubber up to 0.025 in. thick and records holes of 1/64 in. in diameter and larger. Two- and three-position instruments record all holes, count them, and indicate the sections in which they appear. Switches permit testing of each indicating position prior to and during operation. Counter units are electrically actuated and manually reset. The standard model is designed for impressed voltage of 110-volt, 60-cycle ac.—Viking Instruments, Inc., East Haddam, Conn.

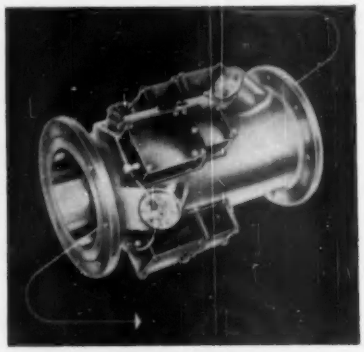
Circle No. 17 on reply card

MEASUREMENT & DATA TRANSMISSION

PRESSURE TRANSDUCER

Piezoelectric zirconate ceramic elements replace barium titanate in a new pencil-type pressure transducer, which is said to provide accurate free-field pressure-time traces for sound or shock waves produced by explosions, passing missles, engine noise or other sources. The piezoelectric coefficient of the zirconate element varies less than 5 percent between minus 60 and plus 70 deg C.—Atlantic Research Corp., Alexandria, Va.

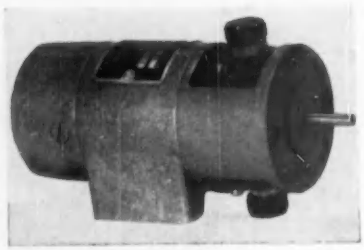
Circle No. 18 on reply card



ULTRASONIC FLOWMETER

Simultaneous readout of mass flow rate, mass totalization, volumetric flow rate, volumetric totalization, and fluid density can be obtained from this flowmeter, which utilizes ultrasonic energy to determine the volume or mass of fluid passing through a smooth-bore sensor. The sensor has no moving parts and does not obstruct free flow of the fluid, and therefore causes no additional pressure drop. The flowmeter will handle up to 720,000 lb or 90,000 gal of jet fuel per hr. It operates equally well in either direction of flow and over wide temperature ranges, giving accuracy within 1 percent regardless of changes in fuel density. The sensor for a 4-in. line is only 10 in. long and weighs only 10 lb.—The W. L. Maxson Corp., Long Island City, N. Y.

Circle No. 19 on reply card

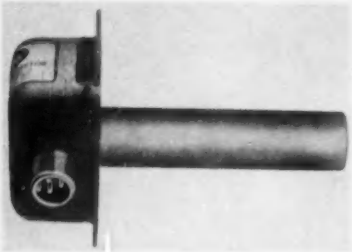


DC TACH-GENERATOR

These new dc tach-generators are available in two basic series, with outputs held to less than 0.1 or 0.25 percent voltage variation due to temperature changes over a range of minus 40 deg to plus 100 deg C. The high accuracy should obviate costly or complicated external compensating networks. Custom built, the generators are available in six basic frame sizes and mounting types, with outputs from 1 to 175 volts per 1000 rpm and standard operating speeds up to 10,000 rpm.—Electric Indicator Co., Springdale, Conn.

Circle No. 20 on reply card

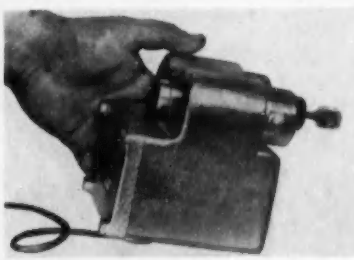
NEW PRODUCTS



COOLING DETECTOR

Designed to detect inadequate cooling of air-cooled electronic components, this unusual detector senses the combined cooling effect contributed by ambient temperature and mass rate of air flow. Having its own sources of heat, it can be set to simulate the temperature condition of the equipment it protects. It can actuate an alarm device or control solenoid- or motor-actuated valves set to produce the additional cooling action required. The detector can be used at air flow rates of 500 to 20,000 lb/hr/sq ft in ambient temperatures of from minus 65 to plus 160 deg R. Heater voltage can be set between 0 and 32 volts, ac or dc. The detector is normally flange-mounted with the sensing leg extending into the duct at right angles to the airstream.—Fenwal, Inc., Ashland, Mass.

Circle No. 21 on reply card



LEVEL DETECTOR

This new control consists of a motor-generator driven at resonant frequency by an ac input. The generator output energizes a relay to control the operation of any type of electrical equipment. For high level detection, the rising fluid halts generator output, stopping the vibrating paddle and causing de-energization of the control relay. For low level detection, the generator output energizes a control relay when fluid level drops, allowing the paddle to vibrate.—Automation Products, Inc., Houston, Texas.

Circle No. 22 on reply card

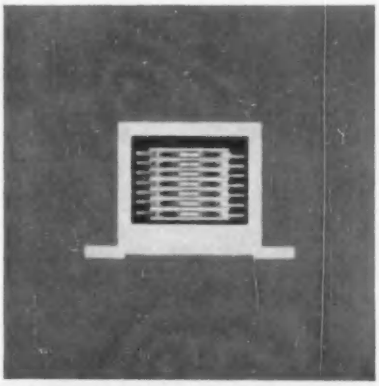
WELDABLE STRAIN GAGES

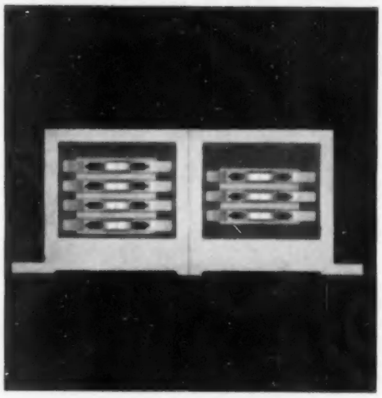
The maker's weldable high-temperature strain gage now has a dynamic test range to 1,600 deg F. It can be spot-welded and test-ready on flat or curved surfaces in less than 5 min, thereby relieving ambient temperature test problems. Two available gage types have a nominal resistance of 120 ohms and a gage factor of 1.80. Dimensions are $1\frac{1}{4}$ in. by $\frac{1}{8}$ in. and $\frac{3}{4}$ in. by $\frac{1}{4}$ in.—Micro-Test, Inc., Los Angeles, Calif.

Circle No. 23 on reply card

PRESSURE TRANSMITTER

Printed circuitry gives a miniaturized line of electronic pressure transmitters operating advantages and high reliability, according to the maker, who claims that errors and effects of ambient conditions are eliminated by a unique electrical feedback system. A Bourdon pressure element connected directly to a balance beam in the transmitter eliminates all linkages and permits sensitivity within 0.001 percent of range span and repeatability within 0.002 percent. Calibration accuracy is within 0.5 percent of range span. Available in ranges from 0-15 to 0-20,000 psi, the pressure transmitters produce an electrical signal of from 1.0 to 5.0





SINGLE STACK versus INTERLEAVED HEADS

for magnetic tape DATA recording

A lively controversy has raged for years over the question, "Are two heads better than one?" Davies, a supplier of both single-stack and interleaved heads finds use for both, and presents a method for choosing the best for your applications.

The original single track recording head left little room for choice or controversy. But as tracks multiplied, and the heads were stacked, troubles developed. More tracks per inch required thinner heads and closer head spacing. But closer head spacing in analog recording increased the intertrack crosstalk. Wider intertrack shielding had to be used, thereby defeating the original need.

Interleaved heads seemed to be the answer. The tracks per head were halved by alternating them on two heads, and mounting the heads side-by-side. Crosstalk became less important for there was no longer a tight limit on shielding width.

Interleaved heads performed handsomely until applied to really precise data work. In aircraft and missile testing, for example, the wave shape on one track is often important only as it relates to wave shapes on other tracks. Unfortunately, time and phase coincidence among tracks is the one thing that interleaved tracks on two heads *can not* provide. By recording a given number of tracks with a single stack head on wider tape, far less phase error is experienced than with interleaved tracks on narrow tape. Thus the pendulum has swung back toward single stack heads, with the proviso that individual heads in the stack be precisely aligned. Typical specifications require that all gaps lie between two straight lines 0.0002" apart, assuring less than 0.2 mil total scatter.

On the basis of proved operating characteristics, these guides have been found extremely useful in finding the right head for a given application:

USE SINGLE STACK HEADS WHEN *time and phase coincidence among tracks are at all important, for in such work precisely aligned single stack heads are absolutely essential. Even when track-jamming is necessary, modern intertrack shielding in a well designed system can reduce crosstalk to a minimum factor.*

USE INTERLEAVED HEADS WHEN *it is essential that a very large number of tracks must be recorded, and considerable time and phase displacement among them can be tolerated, or when compatibility with other equipment using interleaved heads is necessary.*

In digital recording there never has been any controversy. For one thing, crosstalk is not so much of a problem. For another, time and phase coincidence have always been of the utmost importance. If interleaved tracks in two separate heads are used, even the slightest tape stretch or shrinkage between recording and playback completely destroys coincidence of pulses across the tape.

Whichever side of the fence you're on, you're sure to find considerable use for the detailed coverage of the entire head situation given in Bulletin 3301, "Multi-Track Record/Reproduce Heads." Write Davies for your copy.

Davies

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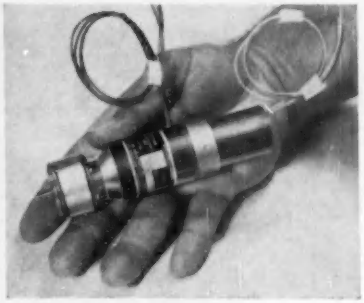
milliamps dc for transmission over distances up to 30 miles.—Manning, Maxwell & Moore, Inc., Stratford, Conn.

Circle No. 24 on reply card



MOTOR-GENERATOR

This synchronous motor-tach generator is a combination of a motor, two-phase generator, and special 3:1 spur gear reducer. It is designed to operate on 115-volt, single-phase, 400-cycle ac and produces 2 oz-in. torque at 4,000 rpm at the output shaft. The generator, a two-phase, sine wave output design producing 20 volts per phase at 200 cps, features harmonic content of less than 5 percent. The unit it suited for use in servo systems or as a drive in a mechanical sweep system requiring a two phase follow up. Generator output can be 400, 200, or 133⅓ cps at voltages to suit individual requirements. Weights are between 12 and 16 oz.—Globe Industries, Inc., Dayton, Ohio.

Circle No. 25 on reply card

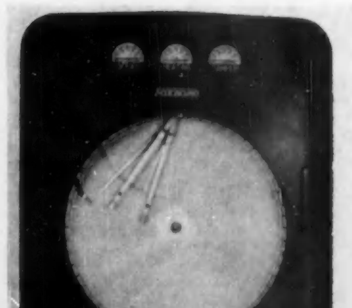
INFORMATION DISPLAY INSTRUMENTS

COUNTER TIMER

A multi-purpose counter timer is designed for precise measurement of frequency, frequency ratio, period (1/frequency), and time interval. Its major features are direct readout with automatic decimal point indication, provision for oscilloscope marker signals for trigger level adjustment of start and stop points, and three independent, continuously adjustable trigger level controls permitting full rated sensitivity at any voltage level between minus 300 and plus 300 volts. Pres-

sure velocity, acceleration, displacement, flow, angular velocity, etc., may be measured with suitable transducers. The instrument may be also used as a secondary frequency standard.—Computer-Measurements Corp., North Hollywood, Calif.

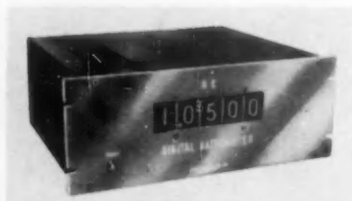
Circle No. 26 on reply card



DRY KILN CONTROLLER

A new series of dry kiln controllers, including both single-zone and multi-zone temperature-humidity recorder controllers, is designed for use in lumber drying operations. They are said to embody the latest developments in controller design and the flexibility required for different type kilns. Both types are available with dual dry bulbs and duplex wet bulb control. On-off wet and dry bulb controls are standard, and narrow band proportional control, particularly useful in damper "whipping", is optional.—The Foxboro Co., Foxboro, Mass.

Circle No. 27 on reply card



DIGITAL DC RATIOMETER

Shown is an instrument which measures the ratio of two dc voltages, E_1 and E_2, where E_1 is derived from E_2, and E_2 drives both the bridge of the ratiometer and the test unit. The measurement is digitally displayed to 5

THIS IS CYPAK

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Now you can break the downtime barrier to further expanding industrial control. Westinghouse CYPAK* provides two bold, new advantages to jump the limitations of mechanical relays.

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Second, CYPAK is given greater protection against the mechanical shocks and corrosive elements of industrial applications. Each component panel is sealed in a solid block of plastic. CYPAK systems are built up from an enclosed power channel into which the CYPAK elements are *plugged in, locked in* securely. Signal terminals are joined with push-on sleeve connectors.

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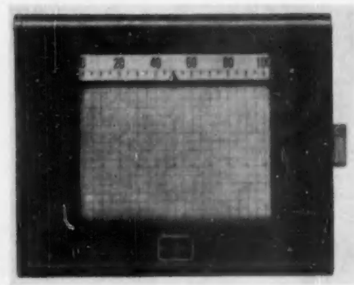
digits on an in-line read-out. The unit measures 7 in. by 19 in. and can be accommodated in standard racks. Power requirement is 75 watts of 115-volt, 60-cycle ac. A switch is located on the rear panel for negative bridge excitation. Optional features include remote readout and printer operation. —Electro Instruments, Inc., San Diego, Calif.

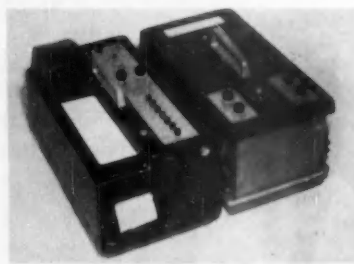
Circle No. 28 on reply card



ELECTRONIC RECORDER

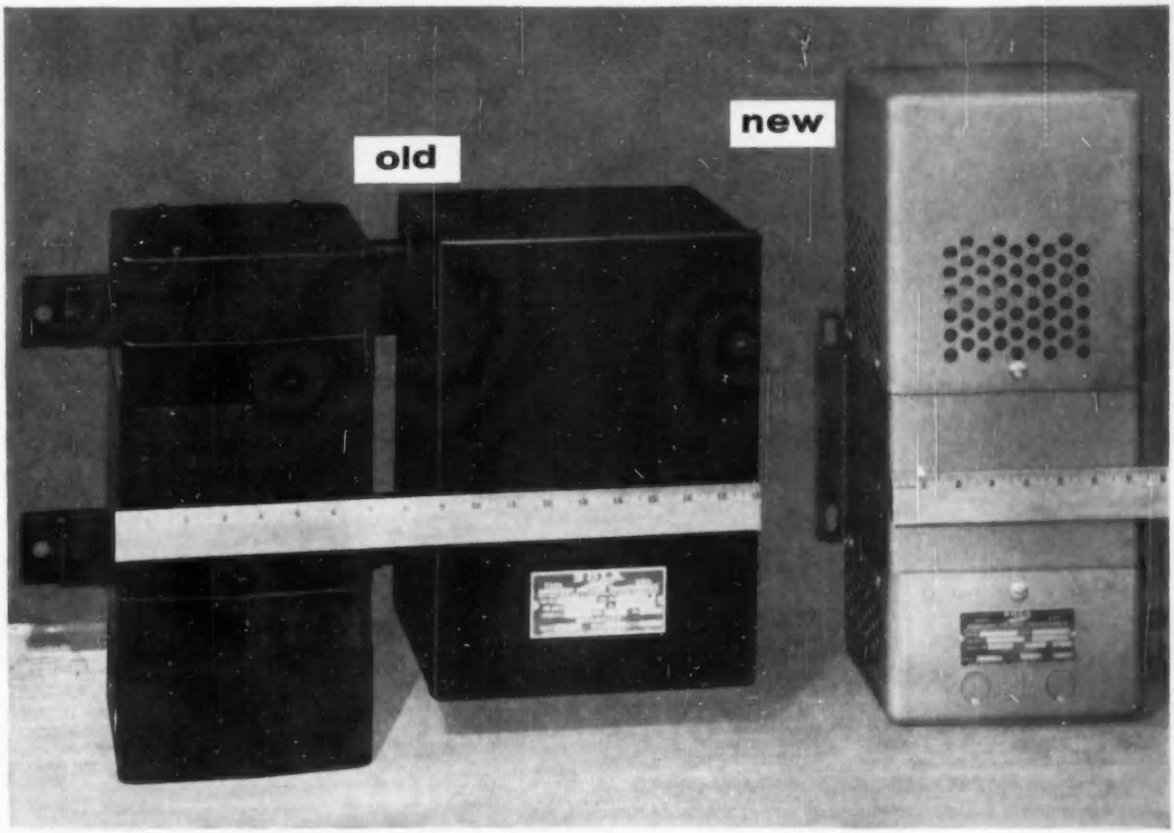
This electronic recorder, part of a new electronic recording system to continuously measure and record the draw speed on a paper machine, receives signals from two tachometer generators and records the arithmetic difference between the two speeds. It is equipped with a three-position manual switch so that either of the speeds may be recorded separately, permitting an operator to make checks on the cycling action of either driving motor.—The Bristol Co., Waterbury, Conn.

Circle No. 29 on reply card



WRITING OSCILLOGRAPH

Shown is a two-channel direct-writing oscillograph which provides instantaneous, permanent recordings of frequencies as high as 250 cps at 1-in. double amplitude. It can record voltages from virtually any source, including magnetic-tape playback units, car-



SMALLER SIZE, LIGHTER WEIGHT *of the new Sola Type CVH regulating transformer design is shown by the comparison of 1000va units shown above. The new unit shown at the right utilizes a single, rectangular housing that replaces the core-and-coil-assembly and separate neutralizer component. Also available in the new design are 250 and 500va capacities. Finish is gray hammerloid.*

New Sola Harmonic-Neutralized Constant Voltage Transformers greatly reduced in size and weight

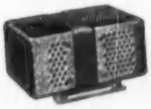
Now the valuable performance features of the Sola Harmonic-Neutralized Constant Voltage Transformer (Type CVH) are offered in a new unit design that provides up to 60% reduced size and 54% lighter weight. In addition to significant size and weight reductions, the new Sola Type CVH regulator design provides the lowest external field of any stock static-magnetic stabilizer available.

Essentially, electrical characteristics of the new Type CVH regulator are unchanged. Stabilization is ±1% regardless of primary voltage swings over a newly-expanded range of 95-130 volts. Sinusoidal output is delivered with less than 3% harmonic distortion at rated load. The nominal output rating has been raised to 118 volts to correspond with similar input reratings of electronic and other equipment.

Sola harmonic-neutralized regulators may be used for the most exacting applications with equipment having elements which are sensitive to power frequencies harmonically related to the fundamental. They are especially suitable for input to a rectifier when close regulation of the dc output is required.

New design Sola Type CVH regulators are available in three capacities — 250, 500, and 1000va. For specific advice on your particular application, consult your Sola representative listed below.

SOLA *Constant Voltage* **TRANSFORMERS**



Request Explanatory Circular

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CONSTANT VOLTAGE TRANSFORMERS • FLUORESCENT LIGHTING BALLASTS • MERCURY VAPOR LIGHTING TRANSFORMERS
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rier amplifiers, audio amplifiers, dc amplifiers, and telemetering discriminators. The instrument's high input impedance makes almost any input device suitable. In addition to frequency response flat to 250 cps, the unit has excellent square-wave and transient response. A vibrating wire in a strong, specially shaped magnetic field burns a contact wherever it touches electro-sensitive paper as it travels over an anvil, providing rectilinear traces.—Consolidated Electrodynamics Corp., Pasadena, Calif.

Circle No. 30 on reply card

RATIO COMPUTER

This pneumatic pressure-ratio computer simultaneously measures compressor inlet and outlet pressures and calculates their ratio, indicating the ratio on an integral scale and generating a pneumatic signal proportional to the ratio. The computer works in static pressure ranges from 0-10 psia up to 0-400 psig. Available for computing with gage or absolute pressures, it can be supplied with either a zero base or suppressed scale indication. Calculating accuracy of the computer is high even when input static pressure turndown ranges are as great as 30 to 1. —Hagan Corp., Pittsburgh, Pa.

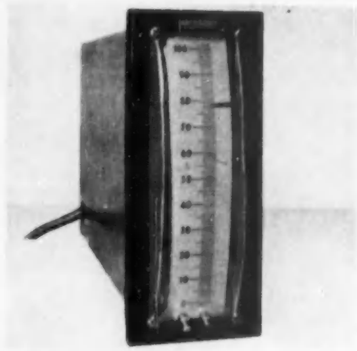
Circle No. 31 on reply card

LOAD CYCLE COUNTER

Differentiating between idling, dry run, and load cycle, a new telemetering load cycle counter will count only load cycles or operations actually performed. It senses the current flow to electrically-driven machines or to tempering, welding, and other electrically-powered operations. The unit is adapt-

able for accurate proximity or impact counting, and can also be used to indicate when to change material, replace dull tools, etc. The telemetering feature permits simultaneous counting at the machine and at a remote location. Ram Meter, Inc., Detroit, Mich.

Circle No. 32 on reply card



SCALE INDICATOR

This new miniature vertical scale indicator, a low-cost, semi-null balance, servo-type instrument, is for use with differential transformer and resistance bulb inputs. Since it is servo-driven, it is said to be more accurate and positive than other meter-type instruments. The semi-null balance circuit minimizes voltage variation and does not require sola or other line voltage stabilizing devices. A fail-safe feature permits the pointer to drop to zero when current fails or when the differential transformer circuit opens. Linearity and repeatability are both within ½ per cent.—Automatic Temperature Control Co., Philadelphia, Pa.

Circle No. 33 on reply card

LINEAR FLOW SIGNALS

Several new high-head differential pressure transmitters, using mercury U-tube measurements, automatically convert differential pressure to rate of flow. These transmitters measure the flow rates of liquids and gases producing maximum differentials from 100 to 1,200 in. of water. The mercury U-tubes operate under maximum service pressures of 800, 3,500, and 6,000 psig. Where mercury is undesirable, a bellows type for maximum service pressures of 1,500 and 3,500 psig is available.—Bailey Meter Co., Cleveland, Ohio.

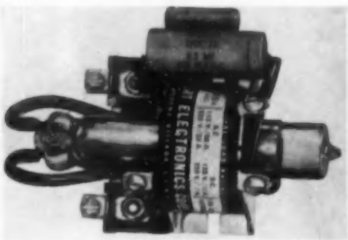
Circle No. 34 on reply card

CONTROL DEVICES

MAGNETIC SWITCH

The core shown here is the "nerve" of a magnetic switch that monitors an assembly-line sequence of parts containing metal, "confirms" each piece as it comes along, and trips a relay to move the part on to the next station. The switch, which has no moving parts, detects objects passing through its magnetic field, shutting down the assembly line if there is a break in the parade of pieces. The laminated iron cores replace bulky amplifiers in the magnetic circuitry of the new flashlight sized switch—Doelcam Div. of Minneapolis-Honeywell Regulator Co., Boston, Mass.

Circle No. 35 on reply card



HIGH POWER RELAY

This special purpose relay prevents damage to fine instrument control contacts by allowing low surge current through the actuating coil. It requires only 0.0035 amp from an external contact (thermometer, contactmeter, probes, etc.) to operate, and has a amplification of 17,300. The relay load rating is 60 amp at 115 vac, 35 amp at 230 vac, and 12 amp at 440 vac on motor, general-purpose, or tungsten lamp loads. Hermetically sealed and with only one non-wearing moving part, the unit is said to be maintenance-free.—Ebert Electronics Corp., Queens Village, N.Y.

Circle No. 36 on reply card

NEW PRODUCTS

LOW COST TIMER

This new multiple-circuit, single interval timer is designed for low cost application where a process is to be turned on manually, run for a pre-selected time, and stopped automatically. Standard models have 1 to 10 circuits and time ranges from 15 sec to 1 hr. Contact closure intervals are adjustable from 0 to 50 percent of the time cycle. The timer dial includes a stop member for use when a particular time setting is to be used repeatedly. A synchronous motor moves the pointer which indicates the amount of time left in cycle. Contacts are rated 15 amp at 115 vac. —Hagen Mfg. Co., Inc., Moline, Ill.

Circle No. 37 on reply card

SENSITIVE SWITCHES

Here is a line of long life, standard limit switches featuring extreme sensitivity and movement differentials less than 0.0005 in. An exclusive snap action mechanism largely eliminates switch fatigue and assures positive actuation of equipment. Since the switches have no pivot points, they have no dead center and no flickering. Mounting centers are a standard 1 in. apart. Switches have standard 15-amp and heavy duty 20-amp ratings.—Illinois Tool Works, Chicago, Ill.

Circle No. 38 on reply card

MINIATURE DC RELAY

A new miniature dc relay features economy and compact size. Measuring

only $\frac{7}{8}$ in. wide, 1 $\frac{3}{16}$ in. long, and 1 in. high, it is claimed to be well suited for use in low cost electronic equipment, expendable devices, printed circuits, autos, etc. Its sensitivity is 40 milliwatts, and its coil resistances are up to 7,500 ohms. Contact rating is 1$\frac{1}{4}$ amp at 115 vac.—Comar Electric Co., Chicago, Ill.

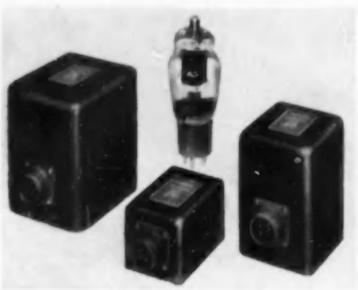
Circle No. 39 on reply card

SWITCHES

A series of electromechanical switches, originally designed for telephone systems, is now available for industrial applications. The switches come in two general types, automatic stepping switches and key switches for manual operation. Principal among the stepping switches is a two-motion, 100-point step-by-step switch, which operates over 10 points in a primary direction and 10 points in a secondary direction. It can search through 100 four-wire circuits to find a particular circuit, select and contact a particular circuit from such a group, or sequence through the 100 circuits. Among the key switches are a wide variety of cam key, indicating, plunger, push button, and twist button types, with locking and interlocking features if desired.—Stromberg-Carlson Div. of General Dynamics Corp., Rochester, N.Y.

Circle No. 40 on reply card

POWER SUPPLIES



DC POWER

The subminiature, magnetic-amplifier type dc power supplies shown here are rugged and stable enough for missile use. They are available in many sizes and ratings from 5 volts for strain gage and transducer operation to 550 volts regulated plate voltage supplies, and contain no vacuum tubes or transistors.—Arnoux Corp., Los Angeles, Calif.

Circle No. 41 on reply card

BATTERY MOTOR

Utilizing the power of a flashlight battery, this new motor can be attached to many recording instruments and charts drives and left unattended for months. It is controlled by a four-jewel balance and a rustproof hair spring which can be regulated for close timing. Available motor voltages are 1½, 4½, 6 and 12 vdc. Torque varies from 0.5 to 9 oz-in. continuous duty, depending on the speed of the output shaft. Motor is enclosed in a dustproof case.—El Products Corp., New York, N. Y.

Circle No. 42 on reply card

DUAL DC POWER SUPPLY

In this dual range dc power supply, which has continuous duty ratings of 0-32 vdc at 40 amp and 0-64 vdc at 20 amp, ripple is held to within 1 percent of the maximum output dc value. It operates on 115 or 230 vac, 60 cycles, single phase. The line voltage selector is equipped with a locking device to prevent accidental switching. Opad Electric Co., New York, N. Y.

Circle No. 43 on reply card

2-LB POWER SUPPLY

Completely electronic dc to dc tran-

sistorized power supplies deliver 50 watts from 24 volts input, weigh only two pounds, and fit in the palm of a hand. Light weight and compact size make them suitable for guided missiles, rockets, aircraft, small boats, and emergency power systems.—Universal Atomics Corp., New York, N. Y.

Circle No. 44 on reply card

DEMODULATOR

The compact, versatile demodulator shown here supplies regulated current to differential transformers and converts their output to dc for use with micrometers and recording potentiometers. Silicon diodes permit demodulation with excellent linearity and stability. The primary supply to the demodulator is 24-volt, 60-cycle ac, allowing use of exposed wires. A calibrating circuit permits both testing at any time without disturbing the transmitting device and compensation for variations in transmission line resistance. No vacuum tubes or choppers are used. It can be located up to 1,000 ft from the transmitter with 4-wire cable and several times farther with 2-wire dc cable.—Automatic Temperature Control Co., Philadelphia, Pa.

Circle No. 45 on reply card

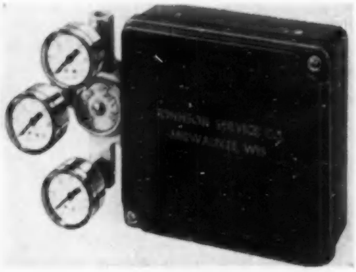
REGULATED DC SOURCE

An improved, tubeless, regulated dc source uses magnetic amplifier circuitry for greater reliability. It is a low-voltage, high-current unit for unattended installations. Input range is 105-125 vac, 60 cycles, single phase.

Output voltage is adjustable between 5.4 and 6.6 vdc. Load range is 0-5 amp, ripple is 1 percent maximum, and recovery time is 0.15 sec.—Sorensen & Co., Stamford, Conn.

Circle No. 46 on reply card

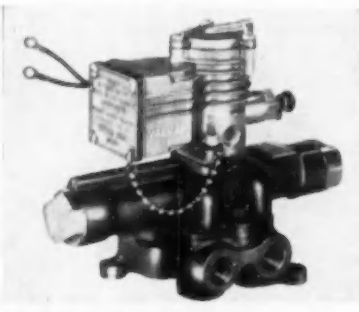
FINAL CONTROL ELEMENTS



PILOT POSITIONER

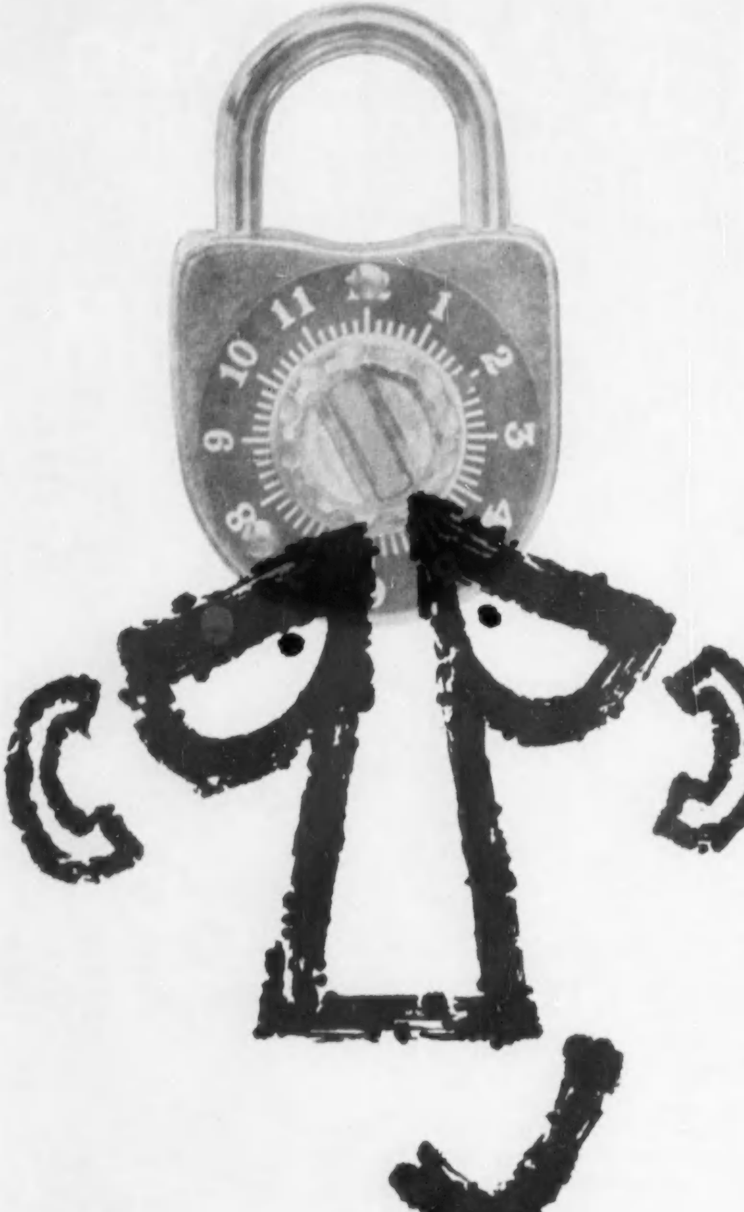
This fast-acting pilot positioner is said to provide extreme accuracy of control in applications requiring precise repositioning for very small changes in controller output pressure. Supply air at 15 to 20 psi is connected to the positioner, with a direct-acting relay transmitting changes in pilot pressure to provide maximum power at all times. Air consumption is exceptionally small. Other features include adjustable starting points and operating ranges, a by-pass switch, and indicating gages.—Johnson Service Co., Milwaukee, Wis.

Circle No. 47 on reply card



SEALED VALVES

A moisture- and dust-proof solenoid enclosure, a safety solenoid cover which renders the valve electrically inoperative when removed, and an integral junction box are features of this series of solenoid valves. Both solenoid cover and junction box cover are fitted with leakage-preventing captive fasteners to prevent loss. Manual override permits operation of valve



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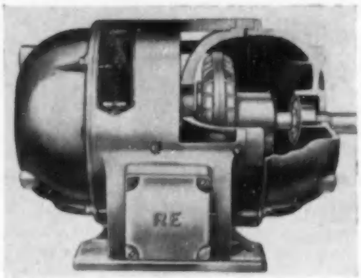
with electrical power off. Valves, which operate at over 600 cycles/min, are said to have a service life in excess of 25 million cycles. They are available in single and double solenoid types, for foot, sub-base, or manifold mounting and in ¼-, ⅜-, ½- and 1-in. pipe sizes. Pilot solenoid coils can be supplied for either ac or dc.—Valvair Corp., Akron, Ohio.

Circle No. 48 on reply card



DRY FLUID DRIVE

This motor provides fluid drive without fluid—by using steel shot. Centrifugal force throws the shot to the housing perimeter, which is keyed to the load and accelerates as the rotor becomes "embedded" in the tightly packed shot. The coupling is mounted inside the motor's frame, and the entire unit is supplied as a single-frame power package. Features include smooth load acceleration, protection against equipment jamming, and ability to start heavy loads on lower, actual operating horsepower. The motors are available in ratings from ½ to 15 hp.—Reuland Electric Co., Howell, Mich.

Circle No. 49 on reply card

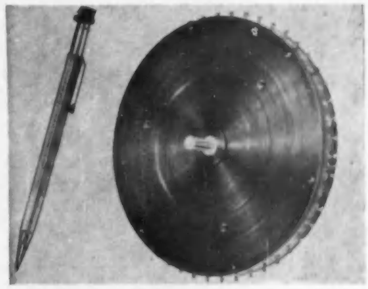
FLOATING DIAPHRAGM

These solenoid valves use a free-floating diaphragm to provide greater fluid flow at lower pressure differentials. They are used for control of water, air, brine, light oils, industrial gas, freon 12 and 22, and other noncorrosive fluids, at temperatures from 0 to 225 deg F, and operate at pressure differentials between 1 and 250 psi. Pilot-operated, with no metal-to-metal contracts, they are said to be practically service-free and guaranteed for 18 months. Port openings range from ⅜ to 1½ in. in diam. Coil assemblies are readily interchangeable.—Jackes-Evans Mfg. Co., St. Louis, Mo.

Circle No. 50 on reply card

NEW PRODUCTS

COMPONENT PARTS



MULTI-TAP POT

The 48 taps in this special precision potentiometer are around a 5-in. diameter and are spaced to give 47 equal resistance sections while maintaining a guaranteed linearity of plus or minus 0.1 percent. Total resistance of 500,000 ohms affords resolution of 0.0075 percent. Positive precious-metal spring contacts with extremely high unit pressures assure permanent vibration-proof contact with low resistance and no linearity distortion at the tap. Other 5-in. models carry up to 74 taps.—The Gamewell Co., Newton Upper Falls, Mass.

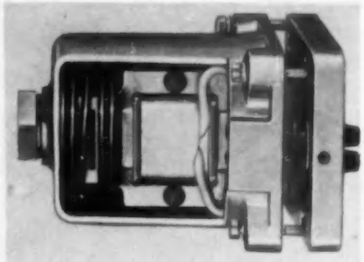
Circle No. 51 on reply card

1½-OZ SOLENOID

This new rotary solenoid, smallest of eight basic sizes, weighs only 1-1½ oz and is 1 in. in diam. Starting torque is 0.2 lb-in. for rotary stroke of 45 deg. Standard rotary strokes of 25, 35, and 45 deg are either clockwise or counterclockwise. Voltage requirements of from 2 to 200 vdc can be accommodated, depending on the coil wire gage used.—G. H. Leland, Inc., Dayton, Ohio.

Circle No. 52 on reply card

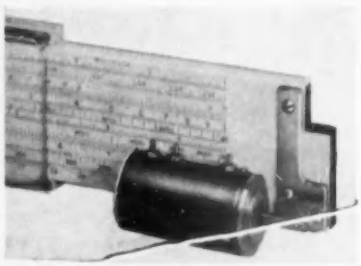
NEW PRODUCTS



OIL-IMMERSED SOLENOID

This oil-immersed solenoid is sealed in a specially designed die-cast case to prevent contamination of the oil. It is slightly larger than a standard model of the same rating when enclosed in a dust-tight cover and is equipped with plug-in contacts for quick installation. The solenoid is fully shock-mounted in two directions and is said to operate 35 to 50 deg cooler than standard models.—Detroit Coil Co., Ferndale, Mich.

Circle No. 53 on reply card



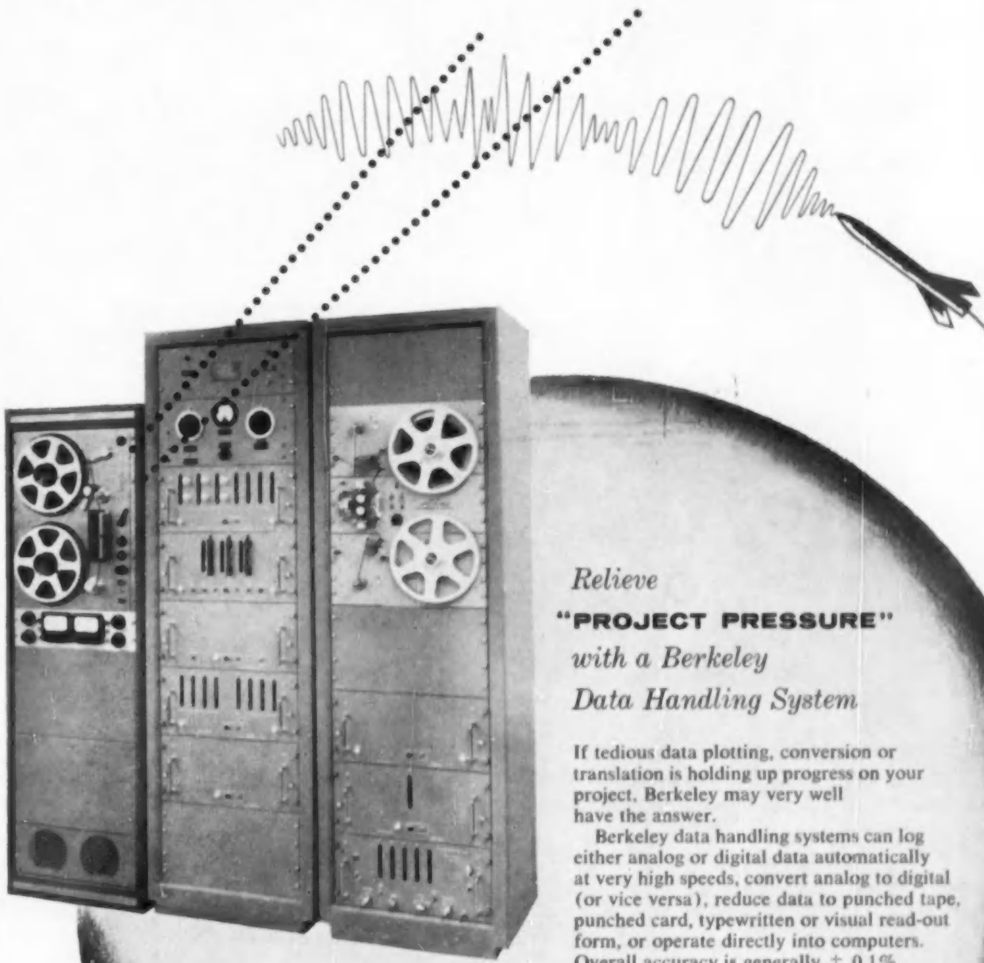
$\frac{7}{8}$-IN PRECISION POT

This $\frac{7}{8}$-in. diam, 10-turn potentiometer features rugged all-metal external construction, stainless steel ball bearings, and glass-sealed terminals positively seated to the housing for mechanical reliability and low leakage path. Terminals are gold-plated for excellent solderability. Resolution as close as 0.008 percent is the result of winding a large number of turns of resistance wire on a mandrel 17 percent longer than previously available.—Litton Industries, Components Div., Mount Vernon, N. Y.

Circle No. 54 on reply card

SNAP-IN RECTIFIERS

A series of new cartridge-type selenium rectifiers, designed for low current, high voltage problems in condenser storage devices, cable testing,



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by Berkeley precisely determines audio frequency output of Sperry 10-C velocimeter to measure missile velocity and coordinates measured in a radial direction. System automatically determines frequency as a function of time, places it in digital form on a magnetic tape handler which is then fed directly into a digital computer for computation of velocity and coordinates. Operates over a 12.5 cps to 12.5 kc input frequency range (50 cps to 50 kc real time). Automatically compensates for tape wow and flutter.

111

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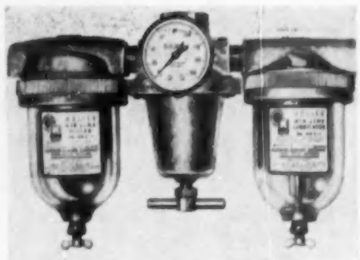
bias supplies, oscilloscopes, etc. are rated at 5 ma dc. They feature low leakage current in the reverse direction, low forward drop in the conductive direction, and a wide frequency range. No filament transformers are needed; neither is warm-up time. The cells are securely mounted in a hard glass tube with a helical steel spring at one end to provide contact. The ferruled ends fit standard 30-amp fuse clips.—Syntron Co., Homer City, Pa.

Circle No. 55 on reply card

ACCESSORIES & MATERIALS



EASY TO CLEAN

This air-line filter-regulator-lubricator drains from the bottom without the bowl being removed. The pressure regulator is inverted to permit more compact installation. Regulator gage has an unbreakable face. The unit is available in any combination or as individual units for ⅜-in., ½-in., or ¾-in. compressed air line. Exterior surface is finished in hammerloid gray.—Keller Tool Div. of Gardner-Danver Co., Grand Haven, Mich.

Circle No. 56 on reply card

RACK FAN

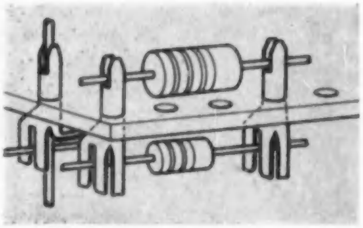
This cabinet cooling fan fits standard 19-in. racks, yet occupies a space only 5¼ in. high. RETMA notching for ready installation, filter, stainless steel grill, and color matching are some of the features. Air delivery is 140 cfm. The motors are so placed that air discharge may be upward or downward. — McLean Engineering Laboratories, Princeton, N. J.

Circle No. 57 on reply card

120-DP GEARS

A complete line of 120 diametral pitch gears, in 14½-deg and 20-deg pressure angles, is now on the market. Hub-type gears come in stainless steel (20-120 teeth) and aluminum (61 to 120 teeth, while hubless gears (aluminum, ⅛-in. face, or assembled with either clamp or solid-type hubs) are available with 121 to 300 teeth. All are stocked in precision classes I and II. Bores range from 0.1200 to 0.1875 in.—Dynamic Gear Co., Inc., Amityville, N. Y.

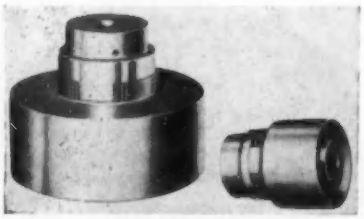
Circle No. 58 on reply card



PUSH-IN TERMINAL

This unusual formed-strip-brass terminal needs only to be pushed into a 0.093-in. hole in a wall or deck, where its partially tubular end is held by spring tension. Staking is not required. The narrow, tapered, serrated slots will firmly grip wire leads of any size between 0.030 in. and 0.045 in. This slot is offset from the axis of the tubular hole so that a riser wire coming up through the hole will not interfere with the cross-wire.—Vector Electronics Co., Los Angeles, Calif.

Circle No. 59 on reply card



FLEXIBLE COUPLING

A new-type flexible coupling incorporates a brake-drum flange on the outer diameter for a compact drive arrangement. This is useful where distance between two units is limited. The new unit is available in eight standard sizes, with ratings of 2 to 40 hp at 1,750 rpm. Maximum bores of the hub body range from 1 to 2¼ in.; drum body bores are made to motor shaft size specifications. Distance between shafts runs from ½ to 1⅞ in. Cushions are one-piece spider type.—Lovejoy Flexible Coupling Co., Chicago, Ill.

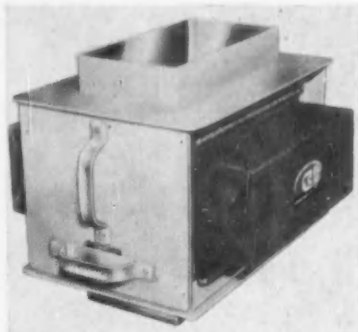
Circle No. 60 on reply card

NEW PRODUCTS

AIR-PRESSURE REGULATOR

A 2-in. pilot-controlled air-pressure regulator not only reduces line pressures from 400 psi max down to working pressures of 2 to 125 psi, but maintains the working pressures. It operates between minus 40 and plus 200 deg F and can be installed at any point in an air system.—C. A. Norgren Co., Englewood, Colorado.

Circle No. 61 on reply card



MAGNETIC FILTER

A new permanent magnetic filter, able to separate micron-size ferrous contamination of high density, dry and liquid materials, consists of stainless steel prongs, magnetically energized by Alnico V castings. The ferrous particles are attracted by the energized prongs and stored out of the flow stream, thus preventing abrasive action. The unit is easily cleaned by breaking magnet contact and removing filter insert. A vibrator unit can be incorporated for special installations.–Magni-Power Co., Wooster, Ohio.

Circle No. 62 on reply card

BATCH COUNTER

The model 99 electronic batch counter is designed for use in production line counting in the range of 0 to 99 counts. While the unit is capable of 4,000 counts per sec, the mechanical indicator on the panel is limited to counts of 1,000 per min. Batch counts up to 999,999 are possible. It also has a spacing adjustment control on the panel to operate internal or external relays and solenoids with delays up to 60 sec.—Spellman Television Co., New York, N. Y.

Circle No. 63 on reply card

UNUSUAL SEALANT

A new liquid sealant, which hardens automatically in the joints between closely fitting metal parts, is said to lock ordinary threaded fasteners so securely that no amount of vibration can shake them loose, yet allow easy removal. The material will remain liquid for months in the original container, and for days when applied as a filter on metal parts prior to assembly.—The American Sealants Co., Hartford, Conn.

Circle No. 64 on reply card

ADJUSTABLE BEARING

This new type ball bearing for linear motion is split longitudinally as shown, providing easy line-to-line or slight preload fit in an adjustable diameter housing. It makes the long-sought objective of free-running no-play linear motion quite practical by enabling the shaft diameter and bearing bore tolerances to be adjusted out, and compensating for wear from severe applications. Bearings come in standard sizes for shaft diameters of 1 to 4 in.—Thomson Industries, Inc., Manhasset, N. Y.

Circle No. 65 on reply card

EXPLOSIVE IGNITERS

This line of explosive igniters for solid propellants and liquid fuels helps to simplify electric initiation systems. Where the igniter requires less than five grams of explosive, the squib is constructed integrally. In larger sizes, the igniter has provisions for accommodating a threaded-in squib. The igniter can be modified or specially designed to fit nearly any situation.—McCormick Selph Associates, Hollister, Calif.

Circle No. 66 on reply card

All Around the Business Loop (from p. 45)

direct activities of the section's digital computer engineering group. Much of the work of this group is of an advanced nature. Johnson, whose doctorate in electrical engineering from Cal Tech is just a year old, has been a research physicist with **Hughes Aircraft Co.** and has worked in GE's **Electronics Laboratory.** He joined GE in 1950.

GE's **Light Military Electronic Equipment Dept.** is filling the biggest Air Force order to-date for advanced airborne electronic countermeasures equipment (radar jammers). Printed-wire circuits provide the equipment with increased margins of reliability, flexibility, and lightness of weight.

► A unique comprehensive index of electronic patents issued last year has been compiled by the Washington, D. C., firm, **Information for Industry, Inc.** Making the survey unique is the process that produced it, a system called "Uniterm", which, according to Information for Industry, utilizes only 2,911 key words in its analysis. Some of the results: 3,130 U. S. patents in electronics issued in 1955; of these, 10 percent (321) held by the federal government, making it the major recipient for the year; 262 issued to **Radio Corp. of America,** putting this company on top among U. S. corporations.

Other figures turned out by Uniterm: 170 patents issued to **Bell Telephone Laboratories;** 118 to **General Electric;** 85 to **Westinghouse;** 51 to **International Telephone & Telegraph;** 50 to **Bendix Aviation;** 44 to **Raytheon Mfg. Co.;** 32 to **Stromberg Carlson;** 30 to **IBM;** 29 to **DuMont Laboratories;** 26 to **Sperry Rand Corp.;** 24 to **Collins Radio;** 23 to **Philco;** 22 each to **Motorola, Sylvania Electric,** and **Hughes Aircraft;** and 19 to **Phillips Petroleum.**

The foreign patent breakdown showed 115 issued to individuals or companies in Great Britain, 40 to Germany, 33 to France, 21 to Sweden, seven each to Switzerland and The Netherlands, four each to Belgium and Canada, two to Morocco, and one each to Italy, Japan, Australia, Czechoslovakia, and Liechtenstein. Not included were 70 patents issued to the **Hartford National Bank & Trust Co.,** trustee for a Netherlands company.

One of the most fascinating figures in the report is the one covering all patents issued in the first six months of this year. This was said to be 3,084, which came close to the 3,130 total for last year.

► It probably surprises no one to learn that aircraft and guided missile manufacturers got more defense business from the federal government last year than any other segment of industry, but it is interesting, nevertheless, to contemplate their exact share. Material for this contemplation has been provided by *The Journal of Commerce,* whose August survey of recipients of military prime contracts shows

Mobile Unit Traces Kinks in Shell Oil Plants

A mobile troubleshooter is being used by Shell Development Co. to aid modification of, and help design, better process control systems for Shell Oil's plants. The instruments in the truck are hooked up to the system under study, and the process operation is upset in some way—usually by changing the signal to a control valve. Inside the truck, Senior Technician Glen Lindsay gathers up to 14 records on a six-channel recorder with six amplifiers. Four triplexers on the recorder permit three records to share one channel. The test equipment also includes a two-pen pneumatic recorder and a 16-point electronic temperature recorder. The data gathered do more than aid in immediate modification: stored in a library, they also help in specifying instruments for plants under construction.

that the plane and missile makers led in 1955 with 25 percent of government orders. The top two companies in the *Journal's* report were **Boeing Airplane Co.**, which grossed $792.2 million in defense money, and **North American Aviation, Inc.**, which finished the year with $790.9 million.

Others high on the list were **General Dynamics Corp.** ($781.7 million); **United Aircraft Corp.** ($587.4 million); **Lockheed Aircraft Corp.** ($412.7 million); **Curtiss-Wright Corp.** ($354.7 million), and **Douglas Aircraft Co.** ($291.9 million).

► **Daystrom, Inc.**, has formed a **Daystrom Systems Div.** in LaJolla, Calif., which will take on projects in automatic control and see them through from design to installation. According to Dause L. Bibby, executive vice-president of Daystrom, the new division "will make available from a single source the information and techniques from the fields of electronics, optics, hydraulics, mechanics, and pneumatics". General manager of the division is Chalmer E. Jones, who comes from **Heath Co.**, another Daystrom unit, where he was assistant to the president. Before that, he was with the **Computer Div.** of **Beckman Instruments, Inc.**

► **Ultra Electric, Ltd.**, of London whose control equipment is used on most advanced turbine engines built in Great Britain, has entered into a 10-year license agreement with **Lear, Inc.**, under which Lear will manufacture and sell the equipment in the U. S.

► **The Perkin-Elmer Corp.** has started expansion of its West German manufacturing subsidiary, **Bodenseewerk Perkin-Elmer & Co., G.m.b.H.**, in response to an increased demand in Europe for analytical instruments. The plant, at Ueberlingen, manufactures P-E infrared spectrometers and vapor fractometers, as well as its own line of cine theodolites, aircraft testing instruments, tape recorders, stereo cameras, compasses, and range finders. Work should be completed in six months.

► The Electro-Way, an electronically controlled continuous weighing system for conveyor-belt handling of bulk materials, will be the first product introduced by **Bell Aircraft Corp.'s** aborning subsidiary, **Bell Automation Corp.** General manager of the new corporation is Frank S. McCullough, with the parent company since 1952, and its officers are Leston P. Faneuf, president; Terence M. Nolan, vice-

president; and William G. Gisel, secretary and treasurer. Faneuf is vice-president and general manager of Bell Aircraft; Nolan is manager of product planning there, and Gisel is secretary and comptroller.

▶ Two prototype instruments and an alarm system for automatically monitoring boiler water will be developed by **Beckman Instruments, Inc.**, for the Navy, which is looking for a way to protect its high-pressure boilers against destructive corrosion. Included in the Navy's request are devices for round-the-clock monitoring of the water's pH and chloride ion content, both critical factors in systems that operate at twice the standard boiler pressure. Beckman's installations, to be used in land-based studies at the **Naval Boiler & Turbine Laboratory** at the Philadelphia Naval Shipyard, will determine the feasibility of further study into these systems.

▶ Ways to apply computer techniques to the solution of operating and engineering problems in the electric and gas industries will be examined by a trio of companies at headquarters established for the purpose in Phoenix, Ariz. "We feel it is important to develop techniques of full use as rapidly as possible," said Walter Lucking, president of **Arizona Public Service Co.**, one of the three companies involved in the study. "By bringing together our separate skills and techniques, we hope to speed this development." The two other companies in the project are **Remington Rand** and **American & Foreign Power Co.**

▶ Operating under a new name and under the guidance of a new chief engineer, **Sargent-Rayment Co.** has diversified activities to include research, development, and manufacturing of nucleonic and industrial electronic devices for commercial and military markets. The new name of the **Donner Scientific Co.** affiliate: **El Dorado Electronics Co.**; its new chief engineer: J. J. Shapiro, previously with **American Instruments Co.**

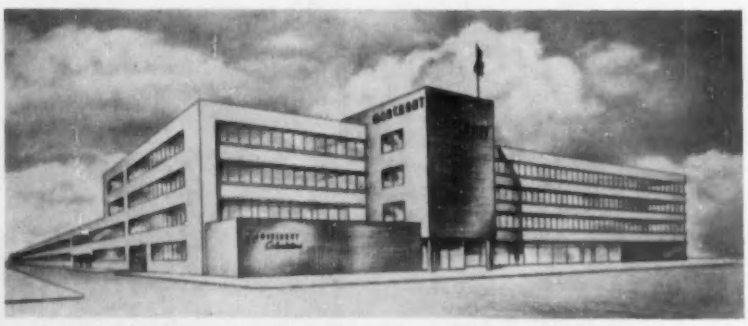
▶ Carrying functional displays of a wide variety of industrial and military timers, time-delay relays, synchronous motors, etc., a motor coach owned by **Cramer Controls Corp.** (formerly **R. W. Cramer Co.**) is touring major American plants to promote familiarity with the company's line. A lecturing engineer is on board.

Companies A-Building

▶ A world headquarters building for **Marchant Calculators, Inc.** ($4 million, 500,000 sq ft), which will consolidate all activities now scattered among two factories and ten other buildings in Oakland, Calif. The new structure, which will also be in Oakland, will include a two-story factory and a four-story front section housing executive and administrative offices, the patent department, and the sales, service, engineering, and research division. At the west end of the property, which will push up against Southern Pacific tracks, will be a subfloor for the maintenance and stores departments. Generous windows and decorative exterior brick are some of the other features. Occupancy will begin next summer.

▶ A transformer plant (750,000 sq ft) in Athens, Ga., for **Westinghouse Electric Corp.** The new plant, one story high, is expected to double the output at Sharon, Ga., home of the company's **Transformer Div.** About 1,200 people will be employed at Athens by 1960 under new plant manager Gordon C. Hurlbert, who continues as manager of the **Distribution Transformer Dept.** at Sharon.

▶ Expansion by **Potter & Brumfield, Inc.**: an addition (16,000 sq ft) to its building in Princeton, Ind.; rental of an entire building (15,000 sq ft) in Franklin, Ky., and purchase of land (four acres) in Princeton for



New world headquarters in Oakland for Marchant: 12 scattered buildings into one.

future construction. Production operations will be carried on in the Princeton addition and manufacturing in the Franklin building.

▶ An aviation electronics plant (75-100,000 sq ft) near Phoenix, Ariz., and a companion flight research unit at Phoenix's Sky Harbor Airport, for **Sperry Rand Corp.** The plant, the first to be built, will cost more than $2 million. Work there will begin next spring on electronic flight and engine control systems for advanced aircraft. The airport unit, to follow, will cost about $500,000. Initial personnel requirements are for 500.

Other Business News

▶ Shareholders of **Topp Industries, Inc.**, were to have voted Aug. 24 on the acquisition of **Heli-Coil Corp.** The proposal involved payment by Topp of 100,000 shares of stock worth $2.3 million, convertible debentures worth $900,000, and $500,000 in cash, and would increase Topp's assets to about $8 million, its annual sales to about $10 million. Heli-Coil's line includes patented thread inserts for use in soft materials such as aluminum, magnesium, and plastics, and a "Mid-Grip" insert for securing bolt connections without lock nuts or safety wire.

▶ Among other acquisitions: High quality precision electronic instruments, including large-screen oscilloscopes, of a subsidiary of **Electronics Specialty Co.**, by **Federal Telephone & Radio Co.** of Clifton, N. J., a division of **International Telephone & Telegraph Corp.**; the regulator business of **Burlington Instrument Co.** (the "Synchrostat" voltage regulator) by **Electric Regulator Corp.**, which follows **Texas Instruments, Inc.**, as owner of this line; **Waldorf Instruments Corp.** (hydraulic servo components for aircraft, hydraulic and electromechanical control devices) by **F. D. Huyck & Sons**; and **Thermistor Corp.** of America (thermistors and thermal controls) and **Vibro-Ceramics Corp.** (ultrasonic and medical instruments), by **Gulton Mfg. Corp.**, which will operate the two companies as divisions.

▶ And a merger: **Sorenson & Co.** (power supplies and line voltage regulators) and **Beta Electric Corp.** (electronic instruments and meters).

Important Moves by Key People

▶ The Teleregister Corp. has appointed **Phillip G. Michel** director of

advanced development. For the last seven years, Michel was in charge of development at Potter Instrument Co., where he did considerable digital work. Previous to that, he worked for General Electric, where he received the Charles A. Coffin Award for his work on a digital chronograph.

▶ **Fred J. Fleischauer** has been appointed chief design engineer of The Teller Co.'s Special Machinery Div. He has done machine tool and product research and development for Rockwell Mfg. Co., Mellon Institute, H. H. Robertson Co., and the Dravo Corp.

▶ **John M. Magida**, recently appointed to the newly-created post of director, systems and application engineering, of Davies Laboratories, Inc., had been chief of the Development & Engineering Section for Instrumentation at the Air Force Flight Test Center, Edwards AFB. At Davies he will supervise development and application of data recording equipment for air and ground instrumentation systems. He has engineered the development and installation of navigational aids, including ILS and GCA, in Far Eastern and Pacific areas.

▶ **Leigh Clayton** has been named European area engineer for Logistics Research, Inc. His headquarters will be at the Autronic Computing Center in Stockholm, Sweden. Concurrently, **Edward Ward** was named supervisor of the Logistics Research Applications Div., where he will direct all programming and applications activities and supervise the Contract Computing Service Center.

▶ **Harold W. Rice**, formerly project engineer of the West Coast Research & Development Laboratory of Robertshaw-Fulton Controls Co., has been appointed laboratory director. With the company for 20 years, he has also been director of the division's experimental laboratory. He holds several patents in appliance controls.

▶ Sterling Precision Corp. has appointed **Sol Levine** chief engineer of its Instrument Div. He comes from Edo Corp., where he was chief engineer. Levine has been engaged in designing, developing, and field testing electronic and electromechanical instruments, including radar, loran, computers, and depth recorders.

▶ **Daniel T. Sigley**, former chairman of American Machine & Foundry's guided missile steering committee and associate director of the company's General Engineering Laboratories, has been appointed chief engineer for the Guided Missile Div. of Firestone Tire & Rubber Co. Sigley, who will direct engineering on advanced weapon systems, received the Naval Ordnance Award for his contributions to the development of the proximity fuse. He

P. C. Michel

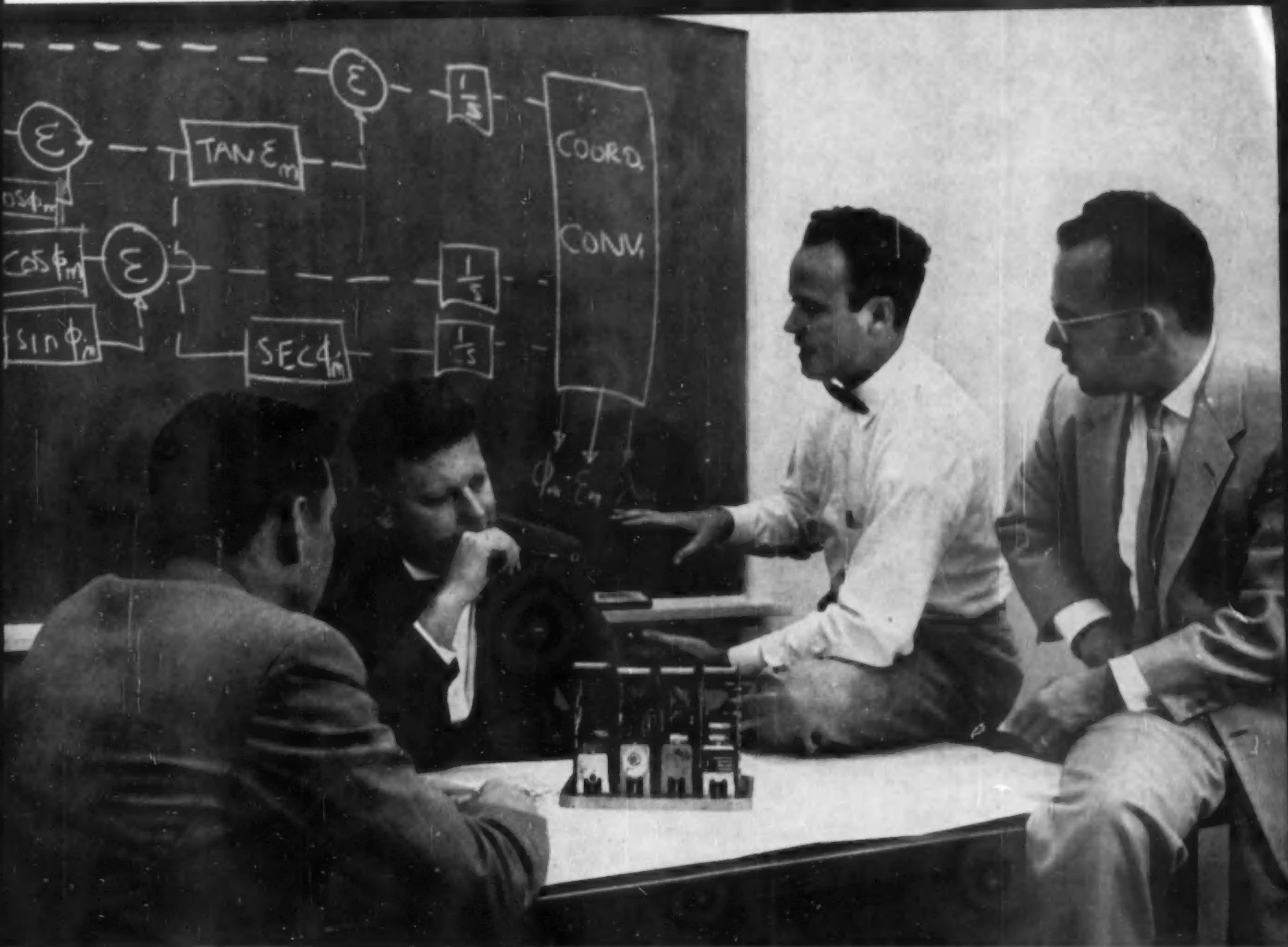
F. J. Fleischauer

J. M. Magida

Leigh Clayton

H. W. Rice

Sol Levine


TAN ε_m
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CONV.
COS ϕ_m
SIN ϕ_m
SEC ϕ_m

D. T. Sigley

D. A. DiTirro

Lionel Glauberman

replaces **Frank MacDonald,** who has been named director of the firm's newly-established Engineering Laboratory at Monterey, Calif.

▶ Valvair Corp. has appointed **Domenic A. DiTirro** manager of research and development. DiTirro, previously research and development manager of Ross Operating Valve Co., will direct new product design, development, and testing, and will supervise the firm's new Research & Development Dept.

▶ **Lionel Glauberman,** onetime manager of the Meter Div. of Hickok Electrical Instrument Co., has been appointed assistant chief engineer of Assembly Products, Inc. He worked in engineering, production, and specification departments before assuming his present position.

▶ **Robert Sackman,** elected vice-president of the Ampex Corp., will continue as manager of the firm's Instrumentation Div. Before joining Ampex, he headed a Department of Defense research branch devoted to the development of recorders and data processing systems.

▶ **Paul W. Koch** was hired away from his Baldwin-Lima-Hamilton Corp. post as general manager of the Cambridge plant by Arthur C. Ruge Associates, Inc., where he will serve as executive vice-president and general manager. Koch's instrumentation experience includes 21 years with Bendix Aviation Corp. and Manning, Maxwell & Moore, Inc.

▶ Powers Regulator Co. has appointed **Robert W. Clark** manager of its Industrial Process Div. Previously a sales engineer for Minneapolis-Honeywell's Industrial Div., he served as the deputy for the Scientific Apparatus Makers Association (SAMA) to the Department of Commerce for six months after joining Powers Regulator.

▶ Clark Controller Co. has named **King D. Christopher** general manager of its newly-established Los Angeles Div., which will include engineering and manufacturing departments and handle Los Angeles area sales.

▶ **Arnold O. Beckman,** president and founder of Beckman Instruments, Inc., has been elected to the board of directors of Marchant Calculators, Inc. He is to serve on the board's executive committee, also.

▶ One of the nation's leading engineers in the high vacuum field, **Russell L. Sylvester,** has joined Rockwell Mfg. Co. as chief engineer of its Central Valve Research & Development Dept. Sylvester was formerly with New York Air Brake Co. as director of project engineering for its Kinney Manufacturing Co. Div.

▶ Eight vice-presidents, five corporate and three regional, have been elected by Minneapolis-Honeywell Regulator Co. The new company V-P's are **Herbert D. Bissel,** formerly director of merchandising; **W. W. Gilmore,** Micro Switch Div. president; **Stephen F. Keating,** former V-P of the Aeronautical Div.; **Kentner L. Wilson,** former Residential Div. manager; and **Gavin S. Younkin,** former general sales manager. The new divisional vice-presidents are **O. B. Wilson,** Industrial Div.; **Melvin P. Fedders,** Aeronautical Div.; and **Charles B. Meech,** International Div.

▶ **Cornelius J. Hes** and **Michael Panich** have been appointed assistant managers of the Design Dept. of Bailey Meter Co. Hes has been with the company since 1927, Panich since 1940.

▶ The Standard Register Co. has appointed **Robert T. Olsen** to the post of assistant director of research. A specialist in organic chemistry, Olsen was a research engineer in organic fibers for the Celotex Corp. of America.

▶ **Paul W. Knaplund** and **J. Hunter White Jr.** have been appointed assistants to the director of the Applied Science Div. of IBM. Knaplund was manager of special products for the Applied Science Div. while White was district applied science representative to IBM branch offices in New York and New Jersey.

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CONTROL ENGINEERING
OCTOBER, 1956

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(100) HYDRAULIC VALVES. Commercial Shearing & Stamping Co. Catalog, 92 pp. Data on performance, capacities, types, sizes, and mountings of oil hydraulic valves for hydraulic-systems designers. Illustrations include photos of installations, cutaway drawings, and flow schematics.

(101) CONTACT PROTECTION. Federal Telephone & Radio Co. Bulletin, 7 pp. Explains operation, uses, and advantages of new selenium contact protectors. First section reviews arcing problem; second describes selenium contact protector; third tells how to select protector.

(102) PRESSURE GAGES. Heise Bourdon Tube Co., Inc. Bulletin, 16 pp. Describes design features, applications, and installation of the firm's pressure gages, with one piece Bourdon tubes machined from solid stock. Ranges to 20,000 psi.

(103) UNBALANCE CORRECTION. Tinius Olsen Testing Machine Co. Bulletin 53, 12 pp. In-place analysis and correction of unbalance is the forte of the portable equipment described here, which normally is applied to parts or assemblies operating between 225 and 36,000 rpm.

(104) JET-RAY DEAERATOR. Cochrane Corp. Publication 4651, 4 pp. Describes deaerator design that eliminates tubular vent condensers without impairing purging of noncondensible gases.

(105) CONSTANT-FLOW PUMPS. The Oilgear Co. Bulletin 46000, 8 pp. Contains capacity and pressure ratings, speeds, and construction and operation details of constant-displacement, radial-piston pumps, which can be used in series or with variable displacement pumps.

(106) ELECTROMECHANICAL COMPONENTS. Servo Corp. of America. Brochure TDS-1110, 12 pp. Presents standard components for design and testing: three terminal assemblies, two dial assemplies, four inertia load discs.

(107) PROTECTED THERMOCOUPLES. Thermo Electric Co., Inc. Bulletin 5, 14 pp. Includes complete information on new miniature protected thermocouples: calibrations, temperature ranges, mounting bushings, terminals, etc. Selector chart aids in specifying.

(108) ARMORED CABLES. Crescent Insulated Wire & Cable Co. Bulletin 356, 12 pp. Gives physical description and various methods of installing the company's cabled tubes. Copper, polyethylene, and other corrosion-resistant materials are available. Accessories for connection and mounting are illustrated.

(109) SHAFT ENCODER. Electronics Corp. of America. Bulletin 4605, 4 pp. Explains principles and provides specs for photoelectric analog-to-digital converter, which reads shaft positions directly with error of 1 part in 8,192. Also describes other encoders with errors as small as 1 part in 65,536.

(110) WALL CHART. Perkin Engineering Corp. 22 by 26 in. Provides tables on temperature conversion, wire sizes, current ratings, decimal equivalents and mechanical conversion.

(111) SOLENOID VALVES. J. D. Gould Co. Single sheet. Specifications and prices of direct-acting solenoid valves of bronze and stainless steel are listed here.

(112) CONNECTORS. DeJur-Amsco Corp. Technical brochure, 12 pp. Covers company's line of printed circuit connectors for $\frac{1}{16}$ in., $\frac{3}{32}$ in., and $\frac{1}{8}$ in. boards, giving photos, drawings, applications.

(113) MAGNETIC DRUMS. Monroe Calculating Machine Co. Bulletin, 8 pp. Describes the Monrobot magnetic drum systems and components, highlighted by a 2-million-bit drum and stacked read/

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(114) AIRCRAFT SWITCHES. Airtite Products, Inc. Bulletin, 4 pp. Gives technical descriptions, illustrations, and wiring diagrams of system switches, time delay units, torque pressure switches, and generator and inverter switches.

(115) EXCITATION SYSTEM. Electric Regulator Corp. Bulletin 5.08, 8 pp. Alternator regulation and control technique is advanced by the McHenry excitation system, which is said to provide extremely fast response, positive stability, close regulation, low cost, and ease of installation. The system, which uses a rotary exciter and an automatic voltage regulator, is explained here.

(116) MULTI-STAGE FLOWMETERS. Fischer & Porter Co. Catalog 10-A-34. The instruments described here provide indication within 0.5 percent of true flow rate between 5 and 100,000 lb/hr. They are primarily for aircraft fuel flow testing and similar applications.

(117) LEVEL SENSING. Simmonds Aerocessories, Inc. Booklet AD-404, 8 pp. Describes liquid-level sensing system that can indicate, start and stop pumps, or operate valves to transfer from one tank to another.

(118) UNIVAC ACCESSORIES. Remington Rand Univac Div. of Sperry Rand Corp. Folder, 10 pp. Contains description of three items aiding in tape data transmission in Univac systems. Transrecorder (magnetic-to-magnetic) allows communication between system units over long distance telephone lines, and two other units convert back and forth between magnetic tape and paper tape.

(119) RECORDING OSCILLOGRAPHS. Consolidated Electrodynamics Corp. Bulletins 1533B, (4 pp.), 1536B and 1500D (16 pp.). Cover three new recording oscillographs. Prices and data on accessories included separately.

(120) MOMENTARY CONTACT. Hetherington, Inc. Bulletin S-2a, 4 pp. Illustrates series W100 pushbutton momentary contact switch and adapters.

(121) TRANSFORMERS. Standard Electrical Products Co. Catalog A56, 22 pp. Single and ganged variable transformers are illustrated and described with photographs, dimension drawings, wiring diagrams, and circuit diagrams. Nine new basic motorized variable transformers are included. Highlight of the catalog: complete specification and application index.

(122) VARIABLE DRIVE. Cleveland Worm & Gear Co. Bulletin, 8 pp. Gives description, principles, operating characteristics, and ratings of variable speed drive. Output speeds range from ⅓ to 3 times input speed.

(123) DRIVES AND CONVEYORS. Link-Belt Co. Catalog, 44 pp. Contains many items, including variable speed drives and bulk-material conveyors. Sixteen types of drives come in ½ to 25 hp capacities.

(124) COMBUSTION AND CONTROL. Cleveland Fuel Equipment Co., Booklet, 16 pp. Reviews the application of control fundamentals to combustion from the standpoints of safety, efficiency, and equipment life, illustrates combustion control, concludes with a "control dictionary".

(125) CONNECTION CHART. Theta Instrument Corp. 5½ in. by 10 in. Presents, in tabular form, synchro null connections based upon new industry standards, providing proper synchro lead combinations for various rotor angles.

(126) METERING PUMPS. Hills-McCanna Co., Booklet 600, 12 pp. The pumps described here continuously meter and proportion chemical additives to water. Pump specs and a table of commonly used chemicals are included.

(127) BRITISH CONTROLS. George Kent, Ltd. Publications 297 and 323, 1 sheet each. Publication 297 describes the firm's microvolt recorder, which records potentials of 0-100 microvolts within fine limits. Publication 323 lists standard ranges of thermocouples, resistance thermometers, and pyrometers made by Kent.

(128) PLASTIC TUBES. Friedrich & Dimmock, Inc., Catalog, 24 pp. Covers tube stock made of clear methyl methacrylate, Teflon, cast acrylic, vinyl, polyethylene, cellulose acetate, polystyrene.

(129) MEMORY DRUMS. Bryant Chucking Grinder Co. Brochure, 4 pp. Motor speeds up to 100,000 rpm are available on the customized magnetic drums described here. They have capacities to 5 million bits.

(130) AIR CONTROL. Airmatic Valve, Inc. Catalog, 72 pp. Illustrates and describes the company's entire line of 2-, 3-, and 4-way air control valves, made for high- and low-pressure installations. Cam, flow-control, foot, hand, interlocking, pilot, pressure-regulator, quick-exhaust, sequence, solenoid, time-delay, and booster valves described; applications given.

(131) DATA SYSTEM. Beckman Instruments, Inc. Bulletin 494, 12 pp. Introduces data processing system designed for chemical processing industries. It is also applicable in pilot plants, weather logging, atomic reactor monitoring, etc.

(132) STANDARDIZED PANELS. Bailey Meter Co. Product specification G71-7, 16 pp. Presents six standard instrument and control panel designs tailored to customer specifications, shipped ready to use.

(133) HUMIDITY INSTRUMENTS. The Bristol Co. Bulletin H1009, 22 pp. Contains information on indicating, recording, and automatically controlling wet and dry bulb instruments and direct-reading psychrometers. Also includes complete line of accessories.

(134) REGULATORS. Atlas Valve Co.

Bulletin 56C, 8 pp. This release, a condensed catalog, deals with automatic pressure, temperature, and level-control valves, reducing valves, pump governors, temperature regulators.

(135) HEATER CONTROL. Westinghouse Electric Corp. Catalog 27-620, 32 pp. Heater control equipment is one of the categories in this catalog of electric heating units and devices. Selection and design charts featured.

(136) SERVO EQUIPMENT. Pegasus Laboratories, Inc. Technical bulletin 100, 4 pp. Contains descriptions and prices of electromechanical and hydraulic actuators, electrohydraulic servo valves, and electronic equipment.

(137) FORCE CONTROL. W. C. Dillon & Co. Bulletin 28E, 4 pp. Gives engineering details, specs, and prices of nine force control switches, with capacities from 100 to 50,000 lb.

(138) MECHANICAL PRODUCTS. Fawick Corp. Bulletin 500-A, 36 pp. Presents the Airflex Div.'s products, including clutches, brakes, couplings, power take-offs, rotorseals, quick-release valves, and high-speed controls. Detailed tables and drawings include dimensions, torque ratings, and other information.

(139) PRECISION POTS. The Gamewell Co. Catalog, 20 pp. Prepared as a technical digest of the firm's potentiometers, catalog covers standard, miniature, sine-cosine, and toroidal units, and is illustrated with photos, dimension drawings, and power rating curves.

(140) MOTORS. U. S. Electrical Motors, Inc. Bulletin 1878, 8 pp. Illustrates one line of U. S. motors, including those with variable speed drives and internal gearing.

(141) OPEN HEARTH. Leeds & Northrup Co. Process data sheet 643(5), 4 pp. Describes oxygen sampling and recording equipment for continuous O_2 analysis of open-hearth waste gases. System includes sampling probe, steam jet sampling system, analyzer, and recorder.

(142) VARIABLE SPEED PULLEY. Reeves Pulley Co. Bulletin V-563, 8 pp. Describes motor pulley available in a variety of capacities between $\frac{1}{4}$ and $1\frac{1}{2}$ hp and speed ratios up to 2.75:1. Also outlines principle of its control.

(143) TORQUE GAGES. Waters Mfg., Inc. Bulletin, 4 pp. Gives mechanical specifications, ranges and direction of measurable torque, and applications for six dial-reading torque gages usable on pots, servos, spring mechanisms, gear trains, magnetic clutches.

(144) VACUUM, PRESSURE GAGES. Hastings-Raydist, Inc. Catalog 140, 4 pp. Vacuum gages read to 100 or 1,000 microns Hg; pressure gages between 0.1-20 or 0.5-5 mm Hg. Electronic manometer measures pressure differentials of a few millionths of a pound per square inch, has $\frac{1}{10}$ in. of water half scale.

(145) FEED CONTROLLERS. The Oilgear Co. Bulletin 44200-A, 12 pp. Four feed controllers for fluid power application provide precision fine feeds and high traverse speeds. Two are variable-displacement, radial-rolling piston pumps for pressures to 1,000 psi, and two are constant-displacement traverse pumps for pressures to 300 psi.

WHAT'S NEW ABSTRACTS

Correlating Process Dynamics

From "The Application of an Analog Computer to the Measurement of Process Dynamics" by P. E. A. Cowley, Shell Development Co. ASME-IRD paper 56-IRD-20, presented at the ISA Conference, New York City, Sept. 17-21, 1956.

Visual frequency response measurements of process dynamics become difficult in practice because distortion and noise obscure information to such an extent that accurate measurements from recorded data may become impossible at the higher frequencies. However, the response at these high frequencies is important in recognizing the process characteristics and in determining the frequency at which 180 deg phase lag occurs. This latter point is particularly important in a process such as the temperature control of an exothermic reaction, where 180 deg phase lag may occur more than once and therefore exhibit conditional stability.

Correlation techniques permit accurate extraction of frequency response characteristics from a process, even in the face of noise and distortion. In this paper, Cowley relates how he applied correlation techniques to a simulated two-time-constant process containing a significant amount of noise and compares results obtained by the visual method with results obtained by the two correlation methods of quadrature components and phase null. In the first case noise so obscured pertinent information on the output records, which were obtained by a sine wave input, that measurement could be made accurately only up to 4 cpm. However, using the correlation methods on the same simulated process, with the same amount of noise, allowed accurate measurements up to 95 cpm.

Cowley's emphasis is on application of the correlation techniques and the practical circuitry necessary to realize useful results. However, by means of an appendix, some of the text, and the references, he also shows that some of the correlation concepts are necessary to the design and use of equipment for extracting a sine-wave from a noisy output signal.

Figure 1 shows the basic setup for obtaining the frequency response by the quadrature components method. "In this method the process output is analyzed as two components, one 'in-phase' with the process input and the other 'in-quadrature' with the process input. . . The correlation computer computes the modified cross-correlation ϕ_{32} and ϕ_{12} which are measures of the in-phase component and the quadrature component of the process output." The amplitude and phase-shifts obtained from these correlations, at frequency of the input sine wave, are:

$$A = \sqrt{(\phi_{32})^2 + (\phi_{12})^2}$$

$$\theta = -\tan^{-1}\left(\frac{\phi_{12}}{\phi_{32}}\right)$$

A typical chart record obtained at one frequency for ϕ_{32} and ϕ_{12} is shown in Figure 2. It can be seen here that to obtain a reading at one frequency requires a large number of cycles, perhaps 15 or 20.

The phase-null method, shown in block-diagram form in Figure 3, provides more accurate measurement than does the quadrature method, but requires more time. The author explains the measurement procedure in some detail when the equipment shown is used in the tests. A typical record is shown in Figure 4. Here, the correlation ϕ_{42}, as found from the record, establishes the amplitude and phase shift at the test frequency, in accordance with the following relationships:

$$A = \frac{2}{m_b}\,\phi_{42}$$

$$\theta = -\tan^{-1}\left(\frac{1-p_b}{p_b}\right), \text{ for } S \text{ at } S_1$$

$$= -\pi + \tan^{-1}\left(\frac{1-p_b}{p_b}\right), \text{ for } S \text{ at } S_2$$

$$\text{where } m_b = \sqrt{1 - 2\,p_b + 2\,p_b^2}$$

The paper includes plots of θ and m_b vs. p_b, the potentiometer ratio.

The block diagrams for the quadrature and phase null methods include a block for the correlation computer. Figure 5 shows this piece of equipment in more detail: appropriate signals entering the computer result in the required cross-correlation outputs from which are obtained the frequency response plots.

The correlation methods discussed use analog computation. However, as pointed out by the author, digital computation can be used, too. Here the data can be recorded on tape in real time and then played back into the digital computer at a faster rate than recorded. This approach can result in considerable savings in money,

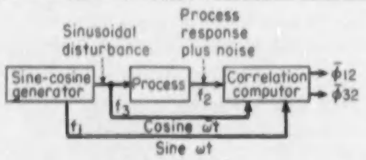


Fig. 1

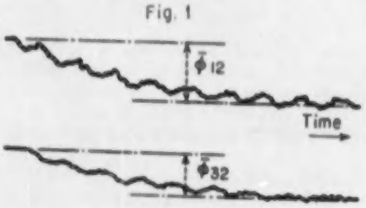


Fig. 2

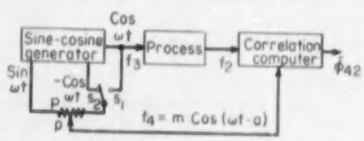


Fig. 3

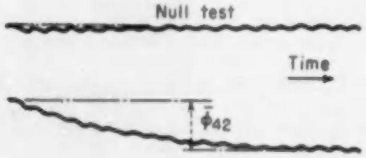


Fig. 4

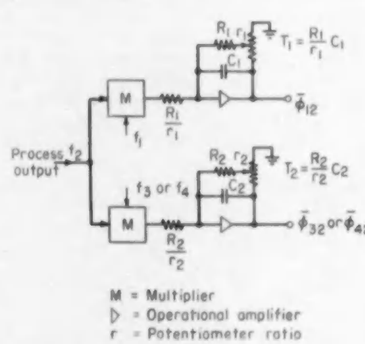


Fig. 5

since the digital computer (at a high cost per hour) will be used for less time.

The particular advantages of the correlation technique are in the frequency-response measurement of "difficult" processes, which Cowley classifies as follows:

- those into which only very small amplitude disturbances may be introduced
- those which are noisy and vary in a random manner in the absence of control
- those which are subject to wide disturbances in the absence of control
- those which are inherently unstable and would run away without control

The disadvantages of the correlation techniques are:

- the need for an analog computer containing at least one, but preferably two, accurate and stable multipliers and integrators
- the need for locating the computer at the test site
- the time required to make the measurements.

The above advantages and disadvantages are taken from the author's discussion of results.

Nonlinear Control Valves

From "The Effect of a Logarithmic Element in an Otherwise Linear Process Control System" by G. L. d'Ombrain and A. Rashwan, Battersea Polytechnic Process Control Lab. (England). ASME-IRD paper 56-IRD-19, presented at the ISA Conference, New York City, Sept. 17-21, 1956.

The importance of nonlinear elements in a process control system, such as an equal percentage valve with a logarithmic form, increases with the size of the deviation introduced into the system. For small deviations it may be satisfactory to assume linearity, but for large ones this assumption may not be valid. The authors select a third-order interacting system and evaluate it on the basis of its having either a linear or a logarithmic modulating unit, with a combination of proportional, rate, and reset actions in the controller.

To perform their evaluation, the authors extend the time-series method of solving differential equations with a nonlinear relationship, originally described by Tustin. The operators

ABSTRACTS

D and $1/D$ are equated to serial operators to effect differentiation and integration, thus:

$$D \equiv \frac{2}{\delta}\ [1, -2, 2, -2, \text{etc.}]$$

$$1/D \equiv \frac{\delta}{2}\ [\tfrac{1}{2}, 1, 1, 1, \text{etc.}]$$

where δ is the interval between consecutive ordinates of the function being integrated or differentiated. Tustin in postulating this method finds certain difficulties with, for example, the integration of a step-unit and the differentiation of a slope unit. The authors of this paper would therefore add the following rules:

"The above statement of method is correct provided that the function on which an operation is performed has:

1) Zero value at the zero ordinate position

2) Zero first derivative at the zero ordinate position."

If the function does not satisfy the first rule, it can be approximated by a zero ordinate of 0.5 times the first ordinate. Then the first ordinate of the result of the operation is discarded. If the function has zero value at the zero ordinate, but does not have a zero derivative there, it can be approximated by a zero ordinate of 0.25 times the value of the first ordinate. Again the first calculated value is discarded. These approximating procedures contributed by the author allow operation on functions formerly hard to handle by Tustin's method.

The authors work out an example of the use of the serial operator on a function that does not have zero value at the zero ordinate:

ordinate position·	0	1	2	3	4
function·	2	4	4	4	4
X $1/D$;	½	½	½	½	½
	½	1	1	1	1
		1	2	2	2
			1	2	2
				1	2
					1
	½	2	4	6	8

Ignoring the zero ordinate yields the ordinates of the integrated curves (since $1/D$ means integrate) as 2, 4, 6, 8 . . . which is correct.

In the major portion of the article, which follows their introduction to this basic numerical technique for determining the output response of the system, the authors evaluate the various linear and nonlinear modulating unit (equal percentage valve) responses under the combination control of proportional, rate, and reset actions. Numerous curves for each type of control compare linear response with nonlinear response under conditions of demand change (load change) and desired value change (step change of input) and with and without valve saturation. The conclusions reached after an investigation of the nonlinear element in closed-loop control by the time-series method are:

1) The equal percentage control valve (a logarithmic function, and hence nonlinear) is suited to conditions of load change;

2) Such control valves give inferior results under conditions of desired value change;

3) Natural saturation of the valve characteristic reduced the bad effects of the desired value changes;

4) These results conform with what is normally observed in practice.

The validity of the computations made by the time-series method was checked by electrical simulation. The authors list the values of the constants for the process, the controller, and the valve, give a painstaking description of the linear and logarithmic regulating units for which the comparison is made, and present a complete discussion of the process characteristics and the control loop.

There seems to have been too little space devoted to the time-series method itself, however. The authors would have done a greater service by dwelling on the details of this technique, even if they had to cut down on the number of variations in control they explored and plotted. The use of examples benefits the reader only if the basic approach is clear. In this case, one must have a good knowledge of Tustin's original contribution or must be particularly adept at grasping the mathematics to bridge the broad gaps left by the authors in going from point to point.

REFERENCES

A METHOD OF ANALYSING THE BEHAVIOR OF LINEAR SYSTEMS IN TERMS OF TIME SERIES, and *A METHOD OF ANALYSING THE EFFECT OF CERTAIN KINDS OF NONLINEARITIES IN CLOSED LOOP CONTROL SYSTEMS*, A. Tustin, JIEE (British), Vol. 94, pp. II A, 1947.

Function Simulation

From "Transfer Function Simulation by Means of Amplifiers and Potentiometers" by L. E. Heizer

and S. J. Abraham, Convair Electronic Computation Lab. Paper presented at the September 1955 meeting of the Association for Computing Machinery and published in the "Journal of ACM", July 1956.

One of the most important applications of analog computers is simulating dynamic systems. Here, properly connected computer elements, such as operational amplifiers and potentiometers, represent portions of the system, each portion being described in terms of a transfer function. This leads to a computer arrangement which simulates that part of the system represented by the transfer function.

The two essential points raised and met by the authors are these: (1) If the transfer function is known, how is the analogous computer arrangement derived? (2) Since there may be several satisfactory arrangements to simulate the system, how is the optimum arrangement obtained? By optimum arrangement the authors mean minimum equipment.

The first step is to rearrange the transfer function into its equivalent operational equation, with the output isolated at the left of the equation. The authors give as an example of this:

$$\frac{e_o}{e_i} = \frac{T_1P + 1}{T_2P + 1}$$

converted to

$$e_o = \frac{T_1}{T_2}\, e_i + \frac{1}{T_2P}\,(e_i - e_o)$$

Inspection of the latter equation leads to the block diagram arrangement shown in Figure 1, which carries out the computation stated by the equation. This computer setup relates the output just as the transfer function did, and the computer simulates the dynamic system represented by the transfer function.

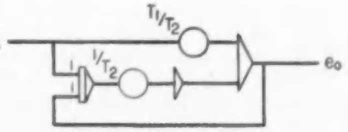
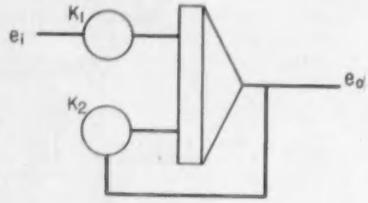


Fig. 1

Another example treats the case of a numerator of second order and a denominator of second order, and shows that here a maximum of five amplifiers and six potentiometers will simulate this transfer function. However, it is usually possible to simulate

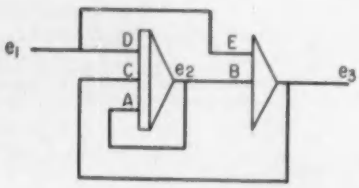
ABSTRACTS

this function with less equipment, by using the two "basic" diagrams shown in Figure 2 and 3 for the general circuit configuration of one and two amplifiers. Connected in series, they simulate any two- to five-element R-C network transfer function with four or less amplifiers. Further rearrangement may lead to the elimination of one or more summing amplifiers.



$$\frac{e_o}{e_i} = -\frac{K_1/K_2}{P/K_2 - 1}$$

Fig. 2



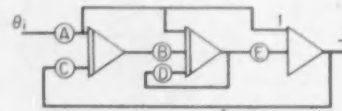
$$\frac{e_3}{e_1} = \frac{A-B}{A-BC}\left[\frac{\dfrac{P}{A-B}+1}{\dfrac{P}{A-BC}+1}\right]$$

for $E = D = 1$,

Fig. 3

Occasionally, the addition of summing amplifiers may be necessary to make available a certain signal for recording. Addition of two summing amplifiers for instance, would leave the transfer function unaltered but would isolate the desired signal. Here is an example: three input signals summed in an integrator yields $-e_o$, but adding two summing amplifiers between the three input signals and the integrator isolates Pe_o.

"By the use of this method [employing the one- and two-amplifier basic configurations] computer networks were derived to simulate any transfer function that may be obtained with one- to five R-C element, three-terminal networks. In addition, computer circuits to simulate second-order systems with any positive damping ratio have been derived using three amplifiers. These circuits pro-



$$K = \frac{A}{C} \quad A = CK$$

$$T_1 = \frac{1}{\sqrt{BE}} \quad B = \frac{T_2}{2T_1(h_2T_1 - h_1T_2)}$$

$$\frac{\theta_o}{\theta_i} = \frac{K(T_1^2P^2 + 2hT_1P + 1)}{T_2^2P^2 + 2hT_2P + 1}$$

$$h_1 = \frac{D-E}{2\sqrt{BE}} \quad C = \frac{T_1^2}{T_2^2}$$

$$T_2 = \frac{1}{\sqrt{BCE}} \quad D = \frac{2h_2}{T_2}$$

$$h_2 = \frac{D}{\sqrt{BCE}} \quad E = 2\left(\frac{h_2}{T_2} - \frac{h_1}{T_1}\right)$$

Fig. 4

vide for convenient variation of natural frequency and damping ratio of the system." Here, derived diagrams mentioned by the authors refer to a catalog of 17 computer diagrams representing 38 different first- and second-order transfer functions. They are of optimum design (use a minimum amount of equipment). Figure 4 shows one of these diagrams, for a second-order system. Here, as with all of the other transfer functions, the relationship of all factors in the transfer function are given so that the computer elements can be determined for the exact set of dynamic conditions to be simulated.

NBS Looks Ahead

From "High Pressure Standards", Summary Technical Report, National Bureau of Standards, U.S. Department of Commerce, Washington 25, D. C., August 1956.

The National Bureau of Standards has undertaken the development of instruments and standards that will permit more accurate measurement of pressures up to 200,000 psi and higher. Pressure-measuring or controlling instruments should, according to the bureau, be calibrated with an accuracy better by a factor of about three than the accuracy within which the instrument is intended to work. In order for industry to control processes within 1 percent, process-control instrumentation should have better than 0.3 percent accuracy, the bench standards for calibrating these instruments should be better than 0.03 percent. The NBS fundamental standard should then be accurate within 0.01 percent. Recent research work requiring even more accurate tools has made these estimates minimal.

One principal effort of the Bureau's

program is the development of piston gages for absolute measurements up to 200,000 psi. Other aims are

- ▶ determination of a series of fixed points on the pressure scale
- ▶ establishment of standards for calibration of dynamic pressure-measuring instruments
- ▶ investigation of electrical-resistance pressure gages

Development work on piston gages is stressing friction reduction between the piston and cylinder. Since they were first constructed in 1952, these controlled-clearance piston gages (clearance between piston and cylinder controlled by an independent pressure applied externally to the cylinder) have undergone a succession of refinements of this type in an effort to reach 200,000 psi.

High pressure fixed points now being investigated are

- ▶ the melting pressure of mercury at 0 deg C (about 110,000 psi)
- ▶ the melting pressure of water at 30 deg C (about 150,000 psi)
- ▶ the transition between crystalline states of bismuth (near 350,000 psi)

Indications are that the carbon dioxide point (boiling pressure 500 psi at 0 deg C) may be the first pressure point for international comparison. Triple points, which are unique in both temperature and pressure, seem to have advantages over the temperature-dependent transformations. The triple points associated with water at 30,000, 50,000, and 90,000 psi will give a three-point calibration covering a range of considerable industrial interest.

Resistance-wire gages, utilizing the pressure-resistance relationship of conductors, are the most-used tools of high-pressure measurement. Temperature effects are minimized by choosing a substance with a negligibly small temperature coefficient at some convenient temperature and then by operating at that temperature. Alloys of manganin or gold chromium are well-suited for the application. Manganin has been used successfully for pressures from 20,000 to 400,000 psi. The problems of external lead resistance and mechanical strain in the sensing element of resistance-wire gages are similar to those in resistance thermometers: they have been solved by a four-wire connection to the resistance coil (two from each terminal of the coil). The Bureau is gathering data on the pressure-resistance characteristics of these gages but will be limited until a primary pressure stand-

ard to 200,000 psi is attained.

The pressure measurements laboratory has started work on a quick-opening valve to be placed between a large volume accumulator and a small volume containing a dynamic gage under test. Opening the valve will produce a pulse whose initial and final pressures can be accurately determined (peak amplitude 50,000 to 100,000 psi). Studies are also being made of a falling-weight type of pulse generator. In this device, a weight falls on a piston which, in turn, transmits a pressure pulse to a confined fluid.

Frequency to Transient

From "Comparison of Several Methods for Obtaining the Time Response of Linear Systems to Either a Unit Impulse of Arbitrary Input from Frequency-Response Data" by J. J. Donegan and C. R. Huss, Langley Aeronautical Laboratory. NACA Technical Note 3701, July 1956. National Advisory Committee for Aeronautics, Washington, D. C.

In analyzing dynamic systems there arises, on occasion, the necessity for finding frequency response data from the transient response of the system when it is subjected to some input, such as a step change. Some examples of this type of analysis were given by Reynolds and Teasdale in the October 1955 issue of CONTROL ENGINEERING. Others can be found in "a concise resume and comparison of methods for obtaining the frequency response from transient response . . .", the subject of the first of the eight references listed by Donegan and Huss. [The references are repeated at the end of this abstract to aid those readers who desire to fully investigate methods of converting from frequency response into transient response, or vice versa, Ed.]

In this present report the authors collect, explain, and compare some of the methods available for performing the reverse conversion, from frequency response to transient response, observing: "It appears that methods of converting . . . data . . . present a flight-data-analysis technique which permits the prediction of aircraft motions and loads for flexible aircraft without knowledge of the equations of motion relating the input and output."

As classified by the authors, the methods fall into three basic cate-

gories, each of which may have several alternatives:

- ▶ Inverse Laplace methods
  - Floyd's method (Reference 2)
  - Numerical integration method
  - Rectangular-pulse method (Reference 3)
- ▶ Fourier method
- ▶ Other methods
  - Schumacher's method (Reference 5)
  - P-transform method (Reference 8)

Initially, the authors compare the exact solution of the response of a second-order system to a unit impulse input with solutions calculated by the above-mentioned methods. They show that the accuracy of all the approximation methods are comparable, and that the accuracy improves as more points are taken. However, the amount of computation time varies with the method used. For the second-order system, the authors rate computation time (as done on a desk calculator) for each method in the following order, the first in the list requiring the least time:

Rectangular pulse
Schumacher's
Floyd's
Numerical integration
Fourier response to unit impulse

For higher-order system, the rectangular pulse method again required the lease computing time, and in general the other Laplace methods were most effective.

It would be impractical in this abstract to review each of the methods described by the authors because of the elaborate graphical and numerical presentations involved. Furthermore, the authors themselves have abstracted, in their 43-page report, much of the literature on individual methods, and even go a step further by applying each method to the same problem and comparing and commenting on the results.

Additional discussion in this technical note covers the application of some of these methods in obtaining the response of the system to arbitrary inputs. Particular emphasis is placed on the use of the Fourier method, and examples are given for square-wave and triangle-wave inputs.

REFERENCES

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Eggleston and C. W. Mathews, NACA Rep. 1204, 1954.
2. Principles of Servomechanisms, G. S. Brown and D. P. Campbell, John Wiley & Sons, Inc., New York, 1948, pp. 332-365.
3. Methods and Tables for Determining the Time Response to a Unit Impulse from Frequency-Response Data and for Determining the Fourier Transform of a Function of Time, C. R. Huss and J. J. Donegan, NACA TN 3598, 1956.
4. An Approximate Method of Deriving the Transient Response of a Linear System from Frequency Response, C. A. A. Wass and E. G. Hayman, Tech. Note No. GW. 1 48, British RAE, November 1951.
5. A Method of Evaluating Aircraft Stability Parameters from Flight Test Data, L. E. Schumacher. USAF Tech. Rep. No. WADC-TR-52-71, Wright Air Development Center, U. S. Air Force, June 1952.
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7. Determination of Frequency Characteristics from Response to Arbitrary Input, "Jour Aero Sci.", Vol. 17, No. 7, July 1950, pp. 446-452.
8. A New Linear Operational Calculus, F. W. Bubb. AF Tech. Rep. No. 6581 (ATI No. 119895). Wright Air Development Center, U. S. Air Force, May 1951.

Briefly Noted . . . .

On-Line Automatic Data Reduction, Tunnel E-1, Gas Dynamics Facility. C. L. Hall and R. E. Klautsch, Arnold Engineering Center, April 1956, 27 pages. (Order PB 111810 from OTS, U. S. Dept. of Commerce, Washington 25, price 75 cents).

The on-line automatic data reduction system described in this booklet reduces data for each test point as a test progresses, and tabulates the data within minutes after completion of the test. The system thus measures, scans, computes, and presents results of wind tunnel tests in one continuous operation. The report explains the operating modes of the system's components during an actual test.

CONTROL PULSES

SHADOWING THE "EYE"

Each of the 39 new radar stations being built for the Dept. of Commerce by Raytheon Mfg. Co. into a nationwide network will be able to pinpoint the exact location of any kind of a storm within a 250-mile radius. The stations make use of a phenomenon which was considered a nuisance by wartime radar operators: reflections or "echoes" of radar waves from precipitation and cloud particles. Raytheon's units, which allow their operators to magnify any particular storm structure on their screens, are said to be able to penetrate deeper into severe storms than anything existing, and thus (1) get nearer to a hurricane's eye, and (2) simplify the plotting of hurricanes as they approach the coast.

FREEZING RADAR RECORDS

A current production instrument, if it had been on board the *Andrea Doria* or the *Stockholm*, might have been able to fix responsibility for the recent collision between the two liners. The instrument is the Mirar, a Fairchild camera which takes pictures of a ship's radarscope at set intervals. It could have determined whether the set was operating at the time of the collision, as well as the speeds of the ships and their relative bearings. The device can also chart navigation aids and fixed instructions in rivers, harbors, and places where channels change.

BRIGHTENING UP PHILLY

Philadelphia is eliminating the last of its gaslights at the rate of 1,000 per year, and it will have them all replaced by 1960, according to Harold E. Mason, street lighting engineer. All street lights are now electric, but there are still some gaslights in the back alleys. The lamplighters are on their way out, too; the new lights are turned on and off automatically at sunset and sunrise by preset Tork astronomical-dial time switches.

TUBELESS COMPUTER

Vacuum tubes are completely replaced by 2-mm-diam magnetic cores in the Decca CI magnetic core computer, which was introduced at London's recent Physical Society Exhibition. Magnetic ferrite cored inductors perform both storage functions and arithmetical operations. The new techniques lead to lowering of power demand and heat output, improvement in reliability, and reduction in cost. Power to operate the cores is provided by thermionic pulse generators; connections are made by printed circuits.

NEW BOOKS

Safety in Numbers

RANDOM PROCESSES IN AUTOMATIC CONTROL. *J. Halcombe Laning Jr. and Richard H. Battin, Instrumentation Laboratory, Massachusetts Institute of Technology. 434 pages. Published by McGraw-Hill Book Co., Inc., New York.* $10.00

Ever feel guilty about your engineering mathematics in comparison to 1956 standards? Here's a fascinating new book that offers a way to assuage your conscience by clarifying many philosophical viewpoints of numbers systems and rendering valid help in satisfying you that you're not ignoring the very real limitations which exist in mathematical representations of engineering problems. Particularly interesting is the treatment of the enormously important viewpoint that any mathematical representation is only as true as the basic postulates of the system are true and representative of the actual process dealt with. A performance index, for example, must actually express the quality of performance involved. The calculus of probabilities, it should be recognized, is concerned exclusively with rules and formal manipulation—not at all with philosophical considerations. Thus your digital analysis may tell you a third is an undetermined number—but if you are dealing with an engineering effort to cut pies in thirds, the problem isn't insurmountable; you just need a more applicable math system.

Lee Avera
Alameda, Calif.

Unlimiting Floyd

THEORY OF A GRAPHICAL FREQUENCY-RESPONSE PROCEDURE FOR CALCULATING TRANSIENT PHENOMENA: WITH TABLES AND NOMOGRAPHS. *(in Russian) V. Solodonikoff, J. Topchev, and G. Krutirova. 195 pp. Published by State Publishing House for Technical Books, Moscow, Russia. Approximately* $2.00

A basic problem in the analysis of an automatic control system is that of determining the transient response from knowledge of frequency response. Some two-score methods are known to the reviewer. Of these, one of the most common is detailed in Chapter 11 of Brown and Campbell's well-known book, *Principles of Servomechanisms*. It is an outgrowth of an MSEE thesis written at MIT in the 1940's by G. F. Floyd (hence known in English as Floyd's method) under the supervision of the authors.

This method involves:

- plotting the real part $R(\omega)$ of the system's overall transfer-function as a function of angular frequency
- approximating the resulting characteristic by a suitably-chosen series of line-segments.
- approximating the actual area under the $R(\omega)$ curve by the algebraic addition of a set of appropriately-chosen trapezoidal areas by the linear segments
- writing the general equation expressing the time response of a system to delta-function input as an integral function of $R(\omega)$
- integrating by using the approximating line-segment characteristic
- calculating time-response from the resulting equation (expressed in terms of the dimensions and areas of the trapezoidal areas)
- using the general equation, numerical values, and graphical plots as approximations to the corresponding exact quantities.

The prime advantages of the procedure are these: the theory underlying it is easily developed and easily grasped; the course of computation with the resulting approximate equations is simple in nature, requiring (*if suitable tables are in hand*) only simple arithmetic computation easily done by slide-rule and/or desk calculator; and any reasonable desired degree of accuracy of approximation can be obtained by a corresponding increase in the number of approximating linear segments.

The essential limitation to this method has been a lack of suitable tables. Available tables do not have a sufficient fineness of incremental increase in the variable or a sufficient number of decimal places in the stated values to enable ready realization of the high degree of accuracy possible with the method.

To tie this discussion of Floyd's method to the book under review, it need only be said that the Russian text effectively eliminates the two aforementioned drawbacks to the method by supplying tables having sufficient fineness and sufficient decimal places. The first part of the book develops general theory; the second illustrates general applications of this theory, such as the determination of transient response from frequency response (as noted above), the determination of frequency response from transient response, and the determination of error coefficients in transient error calculation; and the third, running to roughly 100 pages, contains about 15 mathematical tables of functions needed in the different applications of the general method. A half-dozen nomographs provide useful auxiliary aids.

Much of the theory and many of the illustrative applications set out in the first two parts of the book are to be found in various periodical articles in English. But such is not true of the useful nomographs and extensively tabulated tables of functions. These are readily recognizable and usable by anyone conversant with the associated theory (whether or not he reads Russian).

Numerical Analysis Primer

METHODS IN NUMERICAL ANALYSIS. *K. J. Nielson, Head of Mathematics Div. U. S. Naval Ordnance Plant, Indianapolis, Ind. 382 pp. Published by Macmillan Co., New York.* $6.90

The American Society for Engineering Education was told at its annual meeting in 1954 that "every engineer who has mastered the calculus should also have a course in numerical analysis." Most universities and engineering schools now offer at least a basic course in the subject. This book is written as an elementary textbook for such a course.

Both major categories of numerical analysis (the analysis of tabulated data and the numerical solution of algebraic, differential, integral and other kinds of equations) are treated here, with emphasis on those methods best suited to automatic desk calculators since they are generally available to engineers and scientists. The same methods, however, can be adapted to large-scale computers.

The best-known of the classical procedures developed for desk machines and some of the better recent methods suited to large computers are given. The author believes that a knowledge of this material will permit the user to solve most numerical analysis problems that occur in his investigation.

The subject matter in any course on numerical analysis is here—finite differences, interpolation, differentiation and integration, Lagrangian formulas, ordinary equations and systems, differential and difference

equations, least squares and their application, and periodic and exponential functions—but presented with such clarity that the book deserves to stand alone.

Emphasis centers on the applied, rather than the theoretical, point of view. The practical approach is maintained throughout; methods are presented in a simple manner and with a minimum of mathematical sophistication.

Talks on Computers

Calcul Analogique et Machines Electroniques. *F. H. Raymond, Director of Research, Societe d'Electronique et d'Automatisme, Paris, France.* 180 pp. *Published by Editions de la Revue d'Optique,* 3 *and* 15 *Boulevard Pasteur, Paris, France.* 1955. 1,800 *francs (approximately* $5.25)

These series of talks by a French expert in servomechanisms and electronic computers were made at the National Institute for Applications of the Calculus in Rome, Italy, and originally appeared in the 1952 and 1954 supplementary issues of the Italian journal, "La Ricerca Scientifica".

The first part of the book reviews the basic principles of analog computation and design of electronic analog computers for solution of systems of constant-coefficient linear equations, and discusses stable operation and the accuracy of solutions.

The (shorter) second part is devoted mainly to an account of the construction and functioning of the more complex elements comprising electronic analog computers including amplifiers, multipliers, function generators, etc.

Two official proceedings of the Italian Institute are available. 1) "Analog Computing Conference: Proceedings", Supplement to La Ricerca Scientifica, 1952, 1,000 lire (approximately $1.50); and 2) "Electronics and Television Convention: Proceedings", Supplement to La Ricerca Scientifica, 1954, two volumes, 10,000 lire (approximately $15.00). Both are sold by Consiglio Nazionale Delle Ricerche Ufficio Publicazioni, Piazzale Delle Scienze No. 7, Roma, Italy. The latter includes sections on servomechanisms, digital computers, analog computers, and electronics and cybernetics. The papers are in the original languages, with summaries in French, German and English.

WHAT'S AHEAD: MEETINGS

SEPTEMBER

American Society of Mechanical Engineers, Fall Meeting, Denver, Colo. Sept. 17-20

Instrument Society of America, 11th Annual Instrument-Automation Conference and Exhibit, N. Y. Coliseum, New York Sept. 17-21

Industrial Electronics Conference (no exhibits), American Institute of Electrical Engineers and Institute of Radio Engineers, Hotel Manger, Cleveland Sept. 24-25

OCTOBER

National Electronics Conference, Institute of Radio Engineers, American Institute of Electrical Engineers, Hotel Sherman, Chicago Oct. 1-3

American Institute of Electrical Engineers, Fall General Meeting, Morrison Hotel, Chicago Oct. 1-5

Society of Automotive Engineers, National Aeronautical Meeting, Aircraft Production Forum and Aircraft Engineering Display, Hotel Statler, Los Angeles Oct. 2-6

Armour Research Foundation, Third Annual Computer Applications Symposium (CtE, Sept. '56, page 304), Morrison Hotel, Chicago Oct. 9-10

Conference on Magnesium and Magnetic Materials, American Institute of Radio Engineers, Hotel Statler, Boston Oct. 16-18

National Conference on Industrial Hydraulics, Annual Meeting, Hotel Sherman, Chicago Oct. 18-19

Institute of Radio Engineers, Third Annual East Coast Conference on Aeronautical and Navigational Electronics, Fifth Regiment Armory, Baltimore, Md. Oct. 29-30

NOVEMBER

Instrument Society of America, (Philadelphia Section) Instrument Fair and Symposium on Automatic Data Processing Systems, Bellevue-Stratford Hotel, Philadelphia Nov. 7-8

NMAA, Second Annual Electronic Business Systems Conference, P.O. Box 3584, Rincon Annex, San Francisco, Sheraton-Palace Hotel, San Francisco Nov. 15-16

Third International Automation Exposition and Computer Clinic, Trade Show Building, New York Nov. 26-30

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American Society of Mechanical Engineers, Annual Meeting, National Exposition of Power and Mechanical Engineering, Hotels Statler and McAlpin, Coliseum, New York — Nov. 26-30

DECEMBER

Institute of Radio Engineers, Second Instrumentation Conference, (nuclear instrumentation-industrial applications, missile and wind-tunnel instrumentation), Biltmore Hotel, Atlanta, Ga. — Dec. 5-7

Eastern Joint Computer Conference, Institute of Radio Engineers, American Institute of Electrical Engineers, Association for Computing Machinery, Theme: "New Developments in Computers," Hotel New Yorker, New York — Dec. 10-12

Radio - Electronics - Television Manufacturers Association, Symposium on Applied Reliability, Bovard Hall, University of Southern California, Los Angeles — Dec. 19-20

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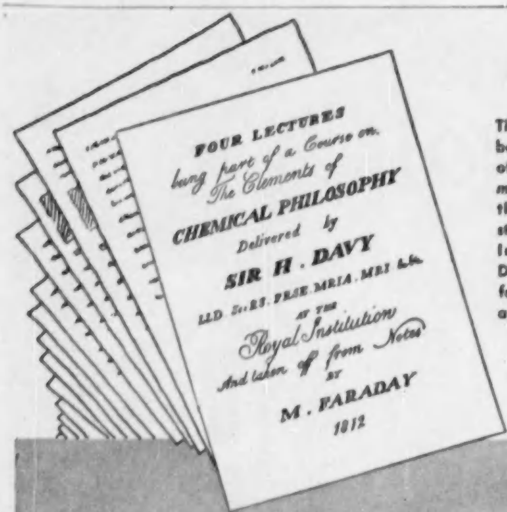

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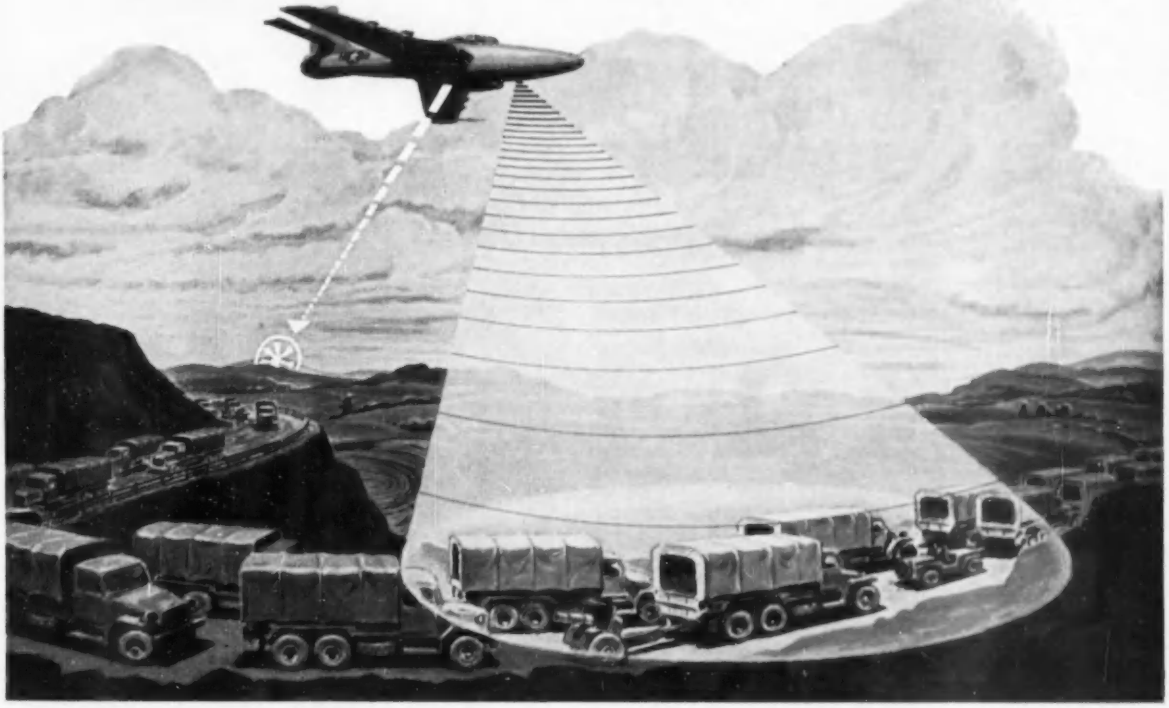

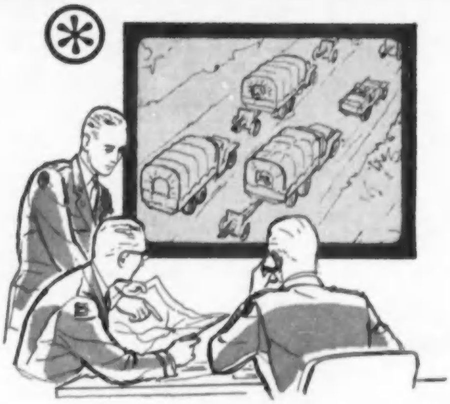

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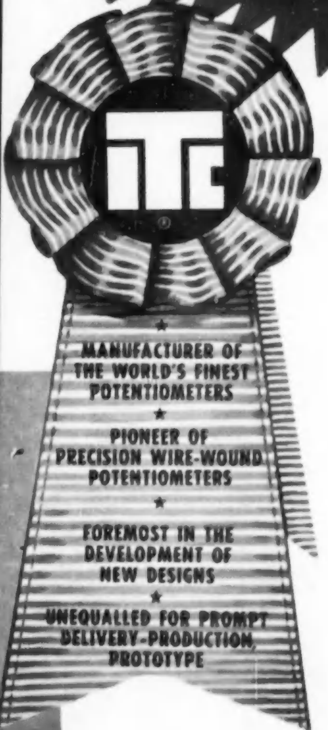

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